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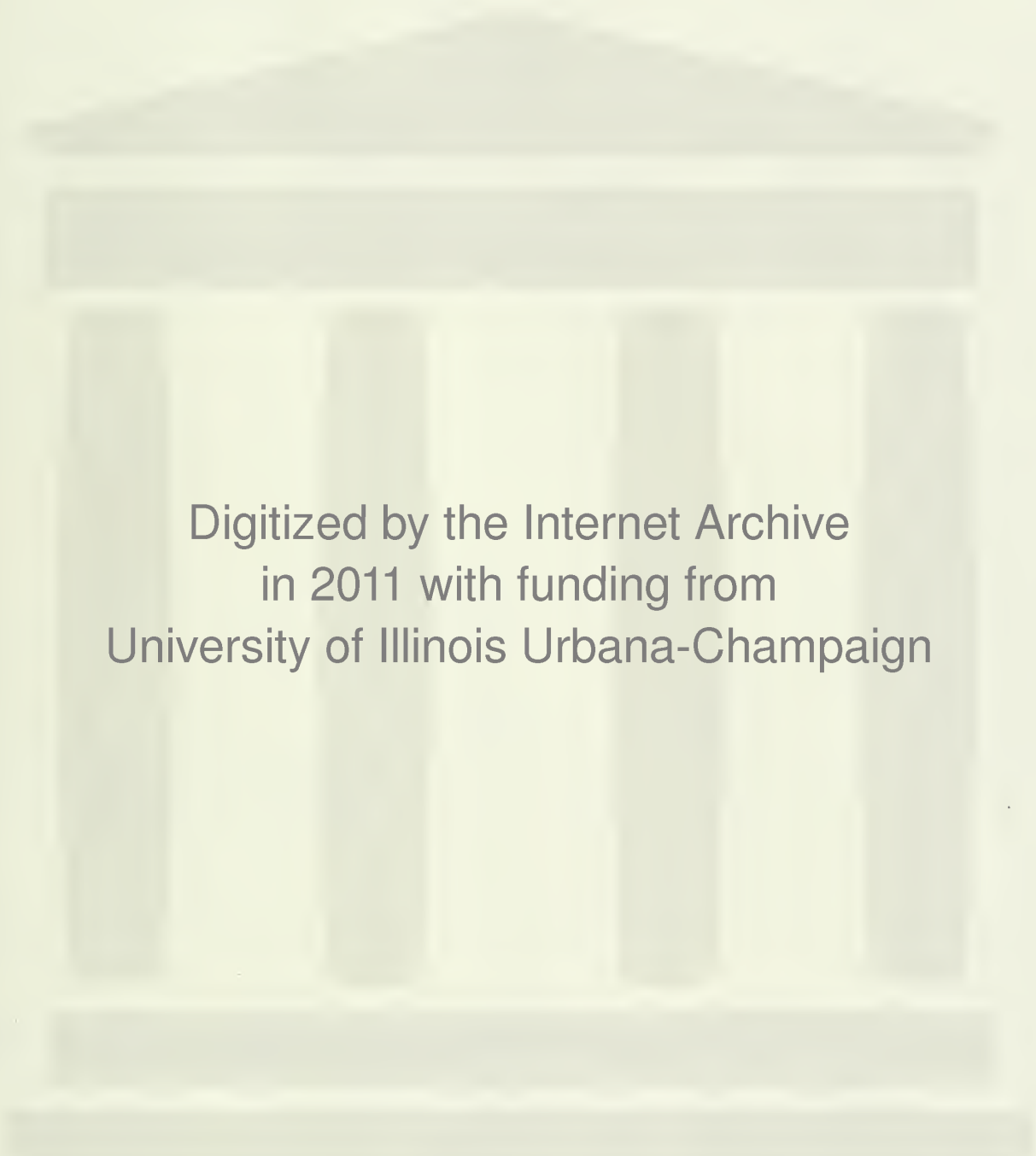

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University of Illinois

PORK INDUSTRY

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University of Illinois

PORK INDUSTRY CONFERENCE

December 4-5, 1978

College of Agriculture
Department of Animal Science
Cooperative Extension Service
Agricultural Experiment Station
University of Illinois at Urbana-Champaign

WELCOME TO THE PORK INDUSTRY CONFERENCE! It is a pleasure to have you attend.

Commercial swine production has become industrialized. It is now a business in which experts in animal production, more than ever, must be concerned about finance, personnel management, labor efficiency, quality control, industry image, government regulation, etc. In other words, it is big business which requires constant awareness of advancements in technology, changes in organizational management and government policies and changes in the factors of production. Only those who make an effort to be informed in all facets of the business will be likely to operate profitably.

This conference is designed to assist swine producers to stay abreast of developments vital to their business. We hope that it will be recognized as and become a part of a continuing education program for professional, large-scale swine producers.

You are here because you need and value information to apply to your business. We hope to provide it.

We will be interested in your suggestions to make future conferences of maximum benefit to you.

D. E. Becker, Head
Department of Animal Science

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THE DEPARTMENT OF ANIMAL SCIENCE

AT THE

UNIVERSITY OF ILLINOIS

THE DEPARTMENT OF ANIMAL SCIENCE IS CONCERNED WITH THE MULTIDISCIPLINARY ACTIVITIES associated with the production, care and utilization of animals useful to mankind. It includes primary fields of study in genetics, environmental physiology and management, meat science and muscle biology, nutrition, reproductive physiology, and some emphasis in aquatic biology and behavior. Beef cattle, horses, poultry, sheep, swine and various companion and laboratory animals are studied to assist animal producers and owners to obtain more efficient performance, more economical production and other such improvements which ultimately benefit the general public.

Our staff includes about 140 people of which 50 are academic staff members, 40 are nonacademic staff members in the offices, research farms and laboratories and about 50 are part-time teaching or research assistants who are pursuing graduate study. Several of the senior academic staff members have received national and international recognition for their accomplishments.

The work of the Department is divided into extension, research and teaching. Extension or off-campus teaching is handled by eight full-time staff members. Each extension specialist conducts seminars, clinics, field days, etc., for livestock or poultry producers. Their primary work is to apply new research findings to the business of animal production or product processing.

Over the years the Department has had very active and productive research programs. Some of the more notable research accomplishments include the discovery of the value of antibiotics in livestock feeding, the elucidation of the amino acid needs of swine and poultry, the utilization of inorganic nitrogen by ruminants, the development of simplified corn-soybean meal rations for swine feeding, and the development of confinement production technics, particularly the use of slatted floors. Current research studies pertain to such topics as recycling of animal wastes, decreasing prenatal mortality in gestating sows, the inheritance of blood groups in swine, and maximizing the utilization of corn stalks by brood cows.

With the recent increase in student numbers, the teaching load in Animal Science has increased significantly. Presently our Department provides instruction for about 2600 students per year in the classroom, and staff members advise 350 undergraduate (mostly juniors and seniors) and 85 graduate majors. Our graduates have many opportunities for employment.

The future of the Department of Animal Science appears bright. Meat consumption and the use of animals for companionship and in recreational activities are at all-time highs and seem likely to increase further. Such an expanding animal industry will require an educational program to produce well-trained animal scientists and research programs geared to produce new and improved technology.

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University of Illinois
PORK INDUSTRY CONFERENCE
December 4 and 5, 1978
Ramada Inn, Champaign

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D. E. Becker	- Professor and Head, Department of Animal Science, University of Illinois
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THOUGHTS
ON
MOTION AND TIME STUDY

Introduction

There is no place where human effort is expended that thought should be given as to how effectively the expenditure of the effort is applied.

The more effort oriented an activity is, the more likely that considerable thought can be directed toward the study to eliminate unnecessary and/or misdirected work for the end result desired.

Work Simplification - First

Perhaps the most difficult thing in the study of work activity is to have a completely open mind during the analysis of a task. But, unfortunately, there is no sure, clear-cut way to study human effort application and come up with a solution. Even the terminology is far from being standard. So, as of today, such study may be known as motion study, work simplification, methods study and/or work design. All in all, whatever term one wants to use, the procedure is relatively the same. Furthermore, it is difficult to realize that the study of human effort is primary with little consideration

of time. As the title of these notes indicates, "motion and time study" is in the prime order as shown; namely, motion study followed by time study. In fact, it is a strong belief that once a thorough motion analysis is made, the time consumed by the task is somewhat automatic. Whereas, time, without a clear indication of the sequence of events, is nearly useless.

Work Simplification - Now

In order to get into what should be, it is necessary to know where one is now. What is done? Who is doing it? Where is it done? Why is it done? This means securing a picture of what is the present status in full detail in the sequence currently being exercised.

How is this picture secured? By actually going through the sequence making detailed notes of each step as the step occurs.

Then, one question is asked of each step in the sequence: WHY?

Further expansion can be:

a. Why do it at all?

b. Can it be eliminated?

c. Why do it at this point in the sequence?

d. Can it be combined with other steps?

e. Can it be done later in the sequence?

f. Are the proper tools being used?

These are only a few questions which can be asked about the present method of accomplishing the tasks. But, above all, one has to be really honest with one's self in asking the question.

Then, the proposed sequence will start to take place with new ideas, suggestions, substitutes, tricks and/or stunts. Remember, there is no standard way to do a job.

At this point, a new, improved sequence can be drawn up to accomplish the sequence. Then the sequence is to be put into use.

The Time

The time necessary to complete the present method is a value. The improved method, with unnecessary work eliminated, will consume less time. But one never knows what the ultimate time is when an improvement in procedure of work tasks are attempted. So, work on the improvement and the necessary time, less than the present time consumption, will be realized.

L.C. Pigage
Professor of Industrial Engineering
University of Illinois
Urbana, Illinois

Housing and Management of Breeding Stock

HANNS-DIETER ALHUSEN

THE HOUSING AND MANAGEMENT FOR INTENSIVE CONFINEMENT PRODUCTION BEGINS WITH THE selection of the breeding stock. Most species will adapt quickly and without great difficulties to sound confinement since it is not a case of "survival of the fittest." And from the humane point of view, research should be conducted to determine whether we are modifying animal behavior and thus defeating the purpose of more economical production. I believe good management with a healthy environment will meet that challenge. Some animals will adapt better than others, and, therefore, proper selection becomes imperative.

The most important area of selection is that for reproductive traits. Right at parturition and at weaning are good times to record or mark selective animals for ease of farrowing, littersize, weight, etc. It is the extra pig going to the packer which shall make the difference. The real story, of course, is how many pigs per sow and year per inventory are marketed. We all know that under normal condition the sow will produce 10-11 live pigs. The question is how many of those we save. Let's not forget that the environment has probably a greater effect than genetics on production (table 1). At about market weight, select the animals that have the best rate of

TABLE 1. GENETIC AND ENVIRONMENTAL EFFECTS ON PRODUCTION[a]

Trait	% due to genetics	Environment
Birth weight	+ 0	+ 100
Littersize weaned	7	93
Weaning weight	8	92
Daily gain	30	70
Feed conversion	30	70
Loin eye area	45	55
Backfat	50	50

[a] Babcock Swine News, Fall, 1976.

gain, feed efficiency, backfat, loin eye area and external reproductive organs. The underline should be uniform with 14 or more nipples evenly spaced and should be able to be recognized from a few feet distance. This is not only important for the female but also for the male. Simple records of the animals' background will be very helpful. Improvements shall be guaranteed if the best animals are selected.

BREEDING:

Confinement means emphasis on management. Management must be in control of scheduling. Therefore, it becomes not a question one can argue about, if pen or hand mating is to be practiced. Hand mating will set the tune. Management must know how many shall or shall not farrow every week, so an orderly to almost capacity flow can be maintained for the efficient operation and labor load of the unit.

Due to the input of the boar, I feel his performance record is 50 times more important than that of the female. Keep the same reproductive records on the male as you do on the female.

The use of the boar should be tailored to his performance and age. Avoid using boars daily! Some boars will have satisfactory conception rates if used only twice a week. With good boars, one mating should be more than sufficient. Many scientific reports indicate that mixed mating will increase littersize and conception, but a single mating with a "good-boar" will be as good or better.

The quiet handling and regimen of the boar does not need to be discussed any further, except during hot weather and the later part of the summer. It is essential that the animals are kept cool and only worked during the coolest part of the day. Ventilation must be adequate to deal with those few hours a day the temperature may be 90° F. A reduced feed intake would also be beneficial. An example of data showing the effects of season on breeding efficiency is shown in table 2.

Even under good environment and management situations, varying from year to year, delayed estrous, particularly in first litter sows, can be a problem. I have found Pregnant Mare Serum (PMS) and Human Chorionic Gonadotropin (HCG) of little value in initiating estrus in the gilt. Breeding more gilts seems to be the best solution at the present time.

TABLE 2. PERCENT OF SOWS IN HEAT ONE WEEK AFTER WEANING FOR EACH MONTH IN 1975, 1976[a]

Month	No. of Sows 1975	% 1975	No. of Sows 1976	% 1976
Jan.	13	92	35	100
Febr.	24	88	64	92
Mar.	34	74	93	96
Apr.	74	81	97	100
May	57	83	79	91
June	49	69	79	91
July	46	70	124	85
Aug.	54	44	83	59
Sept.	59	53	85	76
Oct.	43	52	60	82
Nov.	21	91	43	93
Dec.	14	79	32	88
	488	69.3	874	87

[a] J. P. Hurtgen, Univ. of Minnesota.

GESTATION:

After the sow has been bred, a daily visual pregnancy check - particularly from day 18 to 35 - should be exercised. The sows' condition certainly has great influence on the events later in the farrowing room. Trying to get the sow into a good fleshy condition is one of the harder things to learn. It requires practice and observation. It may be advisable that thin, high performance sows, weaning large litters, not be bred until the second estrus to allow her to put on more weight.

To assure heavier birth weights, 5-6 weeks before parturition feed intake should be increased from 60 to 100%. Everyone is familiar with the low survival rate of lightweight piglets at birth (table 3).

Adequate ventilation in the summer is understood, but a minimum of 50 F room temperature can be dealt with for short periods during cold weather. If longer, feed intake has to be increased, or supplemental heat will be necessary.

Third time rebreeders should be replaced. The trick is to keep only gravid animals, and to rebreed or cull the others without delay. Routinely worm and spray for parasites. Beware of chilling and poisoning.

TABLE 3. SUMMARY OF MORTALITY AND GROWTH RATE OF PIGS OF VARYING BIRTH WEIGHTS[a]

weight per pig (lb.)	No. Pigs	Av. age of dam (years)	Average Weight			% livability		% of weaned pigs surviving to 5 months
			Birth (lbs.)	56 days (lbs.)	154 days (lbs.)	to 56 days	to 154 days	
< 1.4	51	1.45	1.17	21.3	127.0	5.8	3.9	66.7
1.4-1.6	55	1.40	1.47	27.6	159.2	29.1	25.5	87.5
1.6-1.8	73	1.43	1.65	26.8	158.4	31.5	31.5	100
1.8-2.0	136	1.45	1.85	27.5	157.8	41.2	37.5	91
2.0-2.2	166	1.38	2.05	28.2	166.1	48.2	45.2	93.8
2.2-2.4	257	1.41	2.25	30.8	174.4	59.1	55.6	94.1
2.4-2.6	333	1.39	2.45	31.8	175.4	64.6	61.0	94.4
2.6-2.8	362	1.42	2.65	33.6	179.6	71.0	69.1	97.3
2.8-3.0	406	1.49	2.84	33.8	181.9	73.6	70.2	95.3
3.0-3.2	359	1.53	3.04	35.8	186.4	78.3	73.8	94.3
3.2-3.4	353	1.63	3.25	36.9	188.8	82.4	78.5	95.2
3.4-3.6	271	1.62	3.45	36.3	190.0	83.0	79.7	96.0
3.6-3.8	207	1.67	3.64	37.2	189.0	81.6	78.3	95.9
3.8-4.0	141	1.65	3.84	37.6	194.5	85.8	83.0	96.7
4.0-4.2	94	1.73	4.04	39.2	196.5	88.3	88.3	100
4.2-4.4	53	1.90	4.24	38.6	194.4	84.9	77.4	91.1
4.4-4.6	39	1.88	4.45	38.6	196.6	92.3	89.7	97.2
> 4.6	34	1.94	4.74	37.2	202.8	91.2	88.2	96.7

4.4% of all pigs born were dead at birth.

Regression equations:

Birth weight on weaning weight - $Y = 4.09 x + 22.64$

Birth weight on 5 months weight - $Y = 16.63 x + 142.22$

Weaning weight on 5 months weight $Y = 1.93 x + 115.97$

[a] University of Arkansas 1960-1970; 3850 crossbred pigs.

FARROWING:

Pregnant sows should be placed in the farrowing quarters not later than 112 days of gestation. It is understood that the sow should be thoroughly washed and sanitized and put on a light feeding regimen till parturition. After that, it should be washed and sanitized again, plus the litter should be moved to a clean, dry farrowing crate.

For the following week, a close health check should be observed, and prophylactive drugs should be administered only where necessary. The use of a thermometer will be a helpful tool. Feed the sow gradually for the next 7 days twice daily to full feed, meaning: whatever she will consume in about 1/2-3/4 hours time. Her litter size should also be considered.

The room temperature, of course, should ideally vary, cooler for the sow and warmer for the piglets. The temperature for the pig right after parturition is very critical. Any additional source of heat like a heat lamp if necessary should be used to insure the quick drying and maintaining of the piglet's body temperature. Chilling or hypothermia can be a real pig killer or stunter.

Avoid handling the piglets for the first 10-14 days as much as possible. Iron shots, of course, should be administered within three days after birth. Castrating, earnotching, etc., should be delayed to 10-14 days.

Wherever possible, practice the "in and out" concept. In this respect, we can learn from the behavior of certain wild animals. Those keep moving their offspring shortly after parturition, first because of the predators which will be attracted to the decaying placenta, second for disease reasons.

Disease causing agents are always present in order to take the next opportune chance to get virulent, and this can occur when the pig is stressed by chilling, spoiled foodstuffs, inadequate sanitation, etc. Remember, the farrowing and nursery units have almost an ideal temperature for bacteria incubation.

WEANING:

Overall economics almost dictate early weaning of 21 days of age. Two requisites have to be met: adequate food and an above average environment. One should not speak of a least cost ration; instead, search for a ration which is palatable and digestible to the piglet. Any extra amount of skim milk or milk byproduct would be desirable. The facility should be set up as an "all in and all out" concept and be strictly followed.

After each group of pigs is removed, complete cleaning of the room from top to bottom will be necessary. All organic material, fecal material in particular, must be removed. Wet down the clean surface with an effective sanitizer. Any organic matter will neutralize the effectiveness of the disinfectant. Reheat and dry the room to about 80 F floor temperature, before the next group is weaned.

As soon as the piglets reach 20-25 lbs. of weight, if we use a little common sense and knowledge, they are on their way - provided there is no flagrant violation of simple husbandry.

Everybody in the livestock industry is faced with the same problems. But with sound management practices and efficient production, good returns to investment and management shall be assured.

I do disagree very much with people in the industry who will proclaim "the more diseases you have, the more immunity you will receive to protect your herd." You cannot keep diseases out with the motto: "The slums produce the toughest kids." My answer is, they also have the highest mortality.

MANAGEMENT:

The preceding words and thoughts may be enlightening, but the one thing we can not overlook is the fact that somebody has to be able to run the operation, to make it work. The person in charge, male or female, should desirably have an academic agriculture background, not necessarily in swine production, but with the basic understanding and ability to fine tune the operation. A broad curriculum would be more desirable than a specialized one. With a good attitude and love for the chosen field, the practical know how can be gained within a year or two in a well managed operation.

With intensive confinement and its fixed cost, it is our task to produce as many pigs in that unit as possible. We know what the animals are capable of - the only thing we really have to deal with is to give them a chance with a proper environment.

That "system" will prevail which will produce a more economical and better product for the consumer.

A chief executive once described any fixed investment, as it ties down capital, a dog. Management has to insure that that "dog" gets puppies, and all will be smiles.

Saving Baby Pigs

STANLEY E. CURTIS

WASTAGE OF BABY PIGS ON ILLINOIS PORK FARMS AMOUNTS TO AT LEAST 20 PERCENT OF THE piglets born alive. This is a heavy, but reducible, toll. Recent data indicate that around $6\frac{1}{2}$ pigs are weaned from gilts and 8 from sows in this state, yet some producers consistently wean $1\frac{1}{2}$ to 2 more pigs per litter than the average. Although technical knowledge of how to increase baby pig survival has been available for many years, it has not been fully adopted by the pork industry. There are probably several reasons for this. Chief among them is traditional acceptance of these financial losses as part of the cost of producing swine.

Make no mistake about it: every pork producer interested in increasing net profit should seriously consider the cost/benefit ratio for saving baby pigs. The "gilts or sows?" question may have caused some confusion on this point in recent years. It is true that, due to the market value of a spent gilt, and due to the capital-gains tax shelter on breeding animals aged over 1 year when marketed, and despite the smaller litters weaned by gilts, the all-gilt system of breeding-herd management often leads to the lowest after-tax cost per pig weaned. Still, Allan G. Mueller, UIUC agricultural economist and original proponent of the all-gilt system, says that, regardless of the breeding-herd system used, every producer should strive to wean as many pigs per litter as possible without inordinately increasing production cost.

What is the cost/benefit ratio for saving a baby pig? The value of a weaned pig can be taken as the difference between its value as a feeder pig weighing 40 pounds and the cost of rearing it from weaning to 40 pounds. The question is: How much does it cost to save an extra pig per litter? Each producer will need to determine this for himself, and for some the cost may outweigh the benefit. But it is likely that for others, saving more pigs' lives would be a profitable pursuit.

In attempting to arrive at the cost of enhancing piglet survival, keep in mind the fact that most deaths occur during the first couple of days after birth. Early, strict attention to the baby pigs' needs during the newborn period--when the pigs make that huge and marvelous transition to postnatal life--are the most likely to pay off. From practical experience as well as research findings, two factors stand out during this critical period: comfortable environment and attention at the time of birth. Providing these has proved to enhance survival of newborn piglets.

COMFORTABLE ENVIRONMENT

GOEMAAT FARROWING STALL

One operation that has been successful in terms of baby pig survival is Lean Line

---

Stanley E. Curtis is Associate Professor, Department of Animal Science, University of Illinois at Urbana-Champaign.

Pigs at DeMotte, IN. Managing partner Art Goemaat gives much of the credit to farrowing-stall environment for the 9+ pigs per litter that come out of the nurseries at Lean Line. Mr. Goemaat has gone to great lengths to save newborn pigs. He has created a radical farrowing stall that comfortably accommodates both dam and litter. The design incorporates many basic principles of environmental management, and a discussion of it should be useful to anyone contemplating improving the farrowing environment. Following are its major features.

==The stall is 6 feet wide and 8 feet long, considerably larger than conventional farrowing stalls. The Lean Line breeding herd includes mature sows, so the dam's area is a full 2½ feet wide, and it is off-center in the stall: on one side of the dam is a 2½-feet-wide "piglet living area", while on the other side is a 1-foot-wide dunging/nursing area.

==The flooring is unusual, too. Concrete slats 3 feet long and running parallel with the dam are at the back of the stall; most of the dunging/nursing area has a T-bar-slatted floor; and solid concrete covers the rest. Thus, three of the stall's corners are slotted. The fourth one--the one by the dam's head on the piglet-living-area side--is solid.

==A section about 1½ feet long at the front of the piglet living area is 2 inches lower than the rest of the floor. It is recessed in order to hold straw, forming a "nest" for the piglets. A radiant heater serves the nest from above. After farrowing is completed and the piglets have all had their first meal, the whole litter is confined to the nest for a few hours, during which time they become attached to this location. Later, when the baby pigs are not nursing or dunging, they usually are in the nest.

==Before a sow or gilt enters a farrowing stall at Lean Line Pigs, a rubber mat is put down to cover the slotted floor at the back of the stall, and straw is placed on the mat. This straw-covered mat stays there till the piglets are 36 to 48 hours old, and is intended to provide warmth as well as a good footing during this critical period. Straw is not incompatible with slotted floors in this arrangement. During the second day after the pigs are born, the mat is simply picked up, the straw emptied into a wheelbarrow for disposal, and the mat cleaned and put down in another stall.

==The stall perimeter is solid to reduce drafts and low-profile to permit easy caretaker access to both dam and litter.

==The dam has access to a zone-cooling outlet at floor level in the front of the stall during hot weather. Outside air loses some heat to the surroundings in an underground duct system before being blown at the dam's snout. This provides some relief from heat stress in the dam during the summer.

Mr. Goemaat has designed a total facility that is a marvel of mechanization, automation, and efficiency, yet he maintains the industry has gone overboard with the notion of "no-labor" pork production. "It takes work," he says. "It takes concern. I'm good to my animals. In addition to sentimental reasons, it's good business."

THEOBALD FARROWING UNIT

Walter Theobald, large-volume pork producer at Gillespie, IL, also dares to innovate.

He farrows in a variety of accommodations. None of them are conventional, yet all reflect his conviction that, so far as facility design is concerned, "the pigs come first". One model of farrowing unit Mr. Theobald designed recently is especially thought-provoking.

==An 8-feet-square pen is divided so that about two thirds make up a "main area", which serves as dam and piglet living area and holds a self-feeder for the dam, while the remainder is the "toilet", into which the sow steps, leaving young pigs behind. Sows are also free to engage in vigorous prepartal activities.

==The main area has a solid floor that is bedded, preferably with ground cobs or shredded paper. The toilet floor is a slotted, penta-treated-wooden arrangement of Mr. Theobald's design. Two 1-inch X 8-inch planks, butted to provide the major walking surface, lie atop 1-inch-thick strips that run perpendicularly below the top units and in turn on top of single 1-inch X 8-inch planks. Top units are spaced at 6-inch intervals to preclude a pig's getting its foot caught in the floor.

==Pen panels are solid up to over a foot above the floor to reduce drafts.

==A corner of the main area is blocked off with solid planking down to within half a foot above the floor to serve as a brooder for the pigs. A 125-watt bulb or heat lamp supplies supplementary heat when needed and attracts the piglets to the nest.

==Piglet guard rails in the main area are located at the front of the pen (alongside the aisle) and at the back (alongside the toilet).

Mr. Theobald's unique arrangement provides baby pigs with a comfortable environment from birth on, and piglet survival in this unit has been excellent.

ATTENDED FARROWINGS

Around 6 percent of the piglets delivered are stillborn, and only about a third of these can be resuscitated. Over 10 percent of those born alive die during the first day after birth.

Birth is an abrupt and profound environmental change. At birth, the piglet switches from a parasitic intrauterine existence to an independent extrauterine existence. Before birth, the dam provides the piglet with predigested nutrients; afterwards, the piglet must seek, ingest, digest, and absorb nutrients for itself. Before birth, oxygen is transported to, and carbon dioxide from, the piglet's blood via the placental circulation; afterwards, gaseous exchange between piglet and environment depends on the piglet's own external-respiratory functions. Before birth, the piglet is practically sterile; afterwards, the dam no longer protects the piglet from challenges by microbic disease agents. Before birth, the dam's uterus provides the piglet with a constant, comfortably warm thermal environment; afterwards, the piglet is exposed to a fluctuating, uncomfortably cool one and thus must begin to regulate its body temperature. The critical sequence of tasks facing the piglet just before and for awhile after birth make it more remarkable that any survive than that many do not.

The extent of a piglet's adjustment to independent existence during the first postnatal day, and most critically during the first 6 hours after birth, determines its

potential for both short-term and long-term survival. No amount of mechanical contrivances or financial wizardry can replace sound farrowing-time husbandry, the cornerstone of which is the presence of a caretaker who can tend to emergencies as they arise. A common feature of operations in which baby pig survival rate is high is attended farrowings. Admittedly, the dollar value of this activity has not been determined by controlled research and would vary among operations. However, some evidence arose during the conduct of an experiment dealing with another question by B. G. Harmon and P. J. Dziuk of this department. Seventy-five gilt litters were involved and the experiment extended over three farrowing periods. The rate of piglet survival to weaning was phenomenal: 92.5 percent. This rate exceeds any observed at that swine unit before or since. Significantly, a caretaker was present at the birth of each piglet, making sure it took its first breath, drying it off, and seeing to it that the piglet got its first meal.

Commercial pork-production operators should seriously consider having night-time attendants during peak farrowing periods. They could work at odd jobs if no farrowing were in progress so their wages could be charged against more than farrowing alone. However, depending on how it were calculated, the savings in terms of extra piglets might be enough alone to cover the extra cost.

What would the caretaker do, exactly? Following are the major jobs associated with midwifery in the farrowing house.

==Difficult parturition due to a static uterus, blockage of the birth canal by a large pig, or any other reason, frequently results in delivery of dead or weak piglets. When a sow or gilt shows by physical and behavioral signs that she is close to farrowing, she should be observed every few hours until delivery of piglets has commenced, and more frequently thereafter. Symptoms of dystocia should be reacted to quickly by physical assistance or administration of drugs aimed at facilitating parturition.

==Asphyxia immediately before birth is responsible for most stillbirths in swine. About a third of them can be resuscitated if they receive attention immediately after delivery. Further, many liveborn piglets are so asphyxiated during delivery that their survival through the first day or so after birth is jeopardized. Over 80 percent of the stillborn piglets have umbilical cords already disconnected from the placenta when delivered. It seems that premature umbllical-cord rupture explains the severe asphyxiation found in many stillborn piglets and in many of those born alive, but with low viability scores and low chances of survival. Unfortunately, the causes of premature umbilical-cord rupture are not known, so remedies are not available.

==It is common to find a dead piglet in a cool corner of the farrowing stall the first thing on a winter morning. The pig obviously was born alive, but it never received the warmth it needed to survive. Another thing a caretaker can do is check every hour or two for mishaps of this sort. The welfare of the newborn piglet is closely linked with environmental temperature. Surveys usually cite crushing, starvation, diarrhea, and innate weakness as the major immediate causes of piglet deaths. But another condition--chilling--is directly and indirectly responsible for more early piglet deaths than any one of these. Chilling predisposes piglets to crushing, starvation, and disease, and weak piglets are especially likely to be chilled. Rate of piglet survival is directly related with the temperature of the piglets' microenvironment. Piglets are more susceptible to cold stress during the

first day after birth than thereafter. It stands to reason, then, that they need the most care in regard to the temperature environment during the first few hours after birth. Once the piglet reaches 2 days of age without having been severely cold-stressed, its chances of survival are good, if its dam provides enough milk.

==Another important facet of neonatal life is access to colostrum. Recent results of research by J. G. Lecce at North Carolina State University emphasize the need, from the disease-prevention point of view, of ensuring that all piglets within a litter have an equal opportunity to nurse soon after birth. The antibody content of the sow's mammary secretion drops very rapidly after a litter begins nursing. Thus, the piglet that nurses first has the best chance of taking in an adequate number of antibody molecules. In one experiment, half of the piglets in five litters were prevented from nursing until they were 4 hours old, while their respective littermates had access to colostrum from immediately after birth on. At 24 hours of age, the early-deprived pigs had only half as many antibodies in their blood as did their littermates. Some of the early-deprived piglets had serum-antibody levels lower than that considered to confer adequate disease resistance. Of course, smaller or weaker piglets are at a disadvantage regarding opportunity to nurse. The caretaker who comes to the aid of a small or weak piglet even 6 hours after its birth may be too late to ensure enough intake of colostral antibodies by that piglet, again emphasizing the advantage of attended farrowings.

==An occasional gilt or sow becomes savage at farrowing time for no apparent reason and kills its own piglets in a determined fashion. A farrowing attendant can remove the piglets from savage sows as they are born. Often the litter can be returned to the mother several hours later and she will accept her offspring.

==Sows and gilts normally have an elevated body temperature during parturition. This is especially severe during periods of hot weather. It is thought that high body temperature alone is sometimes responsible for prolonged parturition, low milk flow, and even death of the dam. Relief in the form of water applied by a farrowing attendant to the dam's surface with a sprinkler can usually saves baby pigs as well as sows and gilts.

Using Solar Energy in Swine Buildings

J. P. MASON, JR.

TWO SUMMARY COMMENTS FOLLOWING DELIBERATIONS BY A MULTI-NATION GROUP OF OIL EXPERTS assembled recently by the Rockefeller Foundation may very well give us justification for our topic of discussion:

> "There is a high probability that an increasing tightness of international energy supply, especially of oil, will emerge during the late 1980's."
>
> "Energy is a vital pervasive requirement for every society. The world is now in the early stages of an uncertain and lengthy transition from primary reliance on low-cost oil and natural gas to much higher-cost energy alternatives. The transition may occur smoothly or fitfully, equitably or unfairly, or it may prove ultimately to be unmanageable. In any event, the prospects of every citizen in every country will be affected by the outcome." (McElheny, 1978)

The application of solar energy to livestock shelters serves as an "alternate energy source", the most significant justification for extensive study and demonstration is to provide the "smooth transition", and it sure does seem that American agriculture is going to be "affected by the outcome."

Some four years ago, the Energy Research and Development Administration (ERDA) wanted to initiate some solar energy research and demonstration projects in the area of agriculture. It was accomplished with funds passed to and through the United States Department of Agriculture (USDA). Plans were developed by USDA utilizing the Agricultural Research Service and the Cooperative State Research Service, this later group involved the State Agricultural Experiment Stations. Projects were started in 1975, the program continues today, and it appears likely that work through these channels will be maintained for several years to come.

The current program does have a slightly different sound today because almost every agency involved has gone through a reorganization with appropriate name changes. ERDA has been designated as the Department of Energy (DOE). Funds are now passed through USDA to the Science and Education Administration (SEA), where the funds are managed jointly by Federal Research and Cooperative Research of SEA (SEA-FR, and SEA-CS) with the State Agricultural Experiment Stations participating.

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The operational plan for the pass-through funds were developed around five areas of interest:

1. Grain drying
2. Heating and cooling greenhouses and rural residences
3. Curing and drying crops other than grain
4. Heating and cooling livestock shelters
5. Applications of solar energy for food processing (this area was initiated about one year after the previous four).

For project management purposes, a project leader from SEA-FR was appointed for each of these areas, as was a co-project leader representing SEA-CS and the State Experiment Stations. I am presently this co-project leader for the livestock shelters area, and Mr. Dean Winter, Assistant Area Director, SEA-FR, Raleigh, North Carolina, is the project leader.

The livestock shelters area has been funded with some $500,000 for each of the past four years. The fourth series of annual projects got underway this past July, and we are currently in the early stages of selecting projects to begin in July 1979. Ten to twelve projects have been funded each year. Projects have been divided between swine, poultry, and dairy. Project selection has been based on apparent merit of the proposals as well as a distribution among livestock and geographical location. Successful proposals have been funded at land-grant universities and SEA, Federal Research laboratories. Other universities, private industries, and individuals are eligible for consideration.

Currently, livestock shelters solar energy research is being conducted at nine land-grant universities and two SEA, Federal Research laboratories. Four projects are concerned with heating poultry houses to maintain a suitable environmental temperature for efficient production. Two of these are located in the Southeast and are involved with the brooding of chickens. The other two poultry projects are located in the upper Midwest and are investigating solar heating for optimum layer house temperatures maintenance, manure drying, and turkey brooding. Five of the current projects concern swine. Four of these are in the Midwest and are directed to methods of heating swine farrowing, nursery, and grow-out houses. The fifth project is in the Southeast and is studying solar-assisted heat pumps for heating and possibly cooling swine facilities. The final two current solar projects are on dairy, specifically the milking phase of production. Both projects, one in the East and the other in the Southwest, are developing methods to use solar energy for space heating, water heating, and possibly milk cooling.

The basic objective of the solar energy in agriculture program is to identify and adapt existing technology and develop new technology for applying solar energy to agriculture as a viable alternative to the use of fossil fuels. The specific objective of the livestock shelters program is to develop techniques and equipment for substituting solar energy for conventional energy used in operating on-farm livestock production facilities, thereby reducing the dependence of livestock production on depletable fuels. For the current year DOE suggests research should emphasize (1) evaluating the economic feasibility of applications established as technically feasible, (2) developing techniques for using multiple-use collectors, and (3) studying the combining of various energy sources into an energy unit (biomass-solar combination).

SOLAR SYSTEMS

The basic solar system consists of the following four components or subsystems:

1. Solar collector
2. Heat storage
3. Means for heat transport, transfer, and/or delivery
4. System hardware (plumbing, controls, pumps, fans, ducts, etc.).

Sometimes a fifth component, an auxiliary heating device, is included in the above list. The experience of four years demonstrates that there can be a vast difference between the subsystems, but really very little difference between the total systems. The flat plate collector has been the most frequently used collector component and probably holds the greatest potential at this time for animal housing applications. Some systems use air for the heat transport or conveying medium, while others use a combination. Storage of heat is frequently accomplished with rocks or a fluid, but some systems utilize no storage. Heat is delivered through ventilating air, pipes in the floor, area convectors, or heat pumps. The hardware on the systems under development logically include many ideas, false starts, changes in plan, and so forth, frequently resulting in less than impressive assemblies of controls, instrumentation, and plumbing.

Several systems developed and tested through the livestock shelters portion of the Agricultural Applications of Solar Energy Program will be discussed later in this paper. More detail can be obtained from me and/or from the individual project leaders.

SWINE INDUSTRY

National energy consumption for heating environmentally-controlled swine facilities in recent years has been estimated to be in the order of 2 to 4 trillion Btu's annually (22 to 44 million gallons of LP gas equivalent) (Yellott, 1974). The predominate use of heat occurs in the farrowing and brooding phases of production, but sound justification for heating grow-out facilities can be established based on reduced feed consumption. Temperature requirements range from $65^{o}F$ to $85^{o}F$, and heat must be supplied 24 hours per day. Heating demand is seasonal and is, of course, a function of outdoor temperatures.

As stated earlier, a major objective of the agricultural solar energy program is to use solar energy to replace fossil fuels. Space heating meets this criterion, but the reduction of feed consumption does not. Obviously for the producer, it is his option as to how the economics are satisfied and both--fuel and feed--tend to offset the costs involved with solar energy utilization.

Generally speaking, the application of solar energy to dwellings, to industry, or to swine housing has been in concert with good practices of heat conservation. This includes reasonable insulation of the structure, adequate ventilation operated properly, and the practice of maintaining adequate animal numbers or animal density. Surely, a spin-off from the various solar energy projects will be an appreciation for good heat conserving practices.

SWINE FINISHING UNIT, UNIVERSITY OF NEBRASKA

A study has been conducted to evaluate the under-floor mass for the storage of solar heat to increase the floor temperature for a swine growing-finishing building in the winter (DeShazer, 1977). The facility used is one that is completely enclosed during the winter but can be opened on the south during the summer. This type of building is termed a modified-open-front. Two types of solar collectors were used: a passive collector arrangement of southern exposed translucent panels which allowed solar energy when available to warm the floor, and active collectors located on the roof with necessary fans and ducts to move the warmed air from the roof collectors down to channels formed with masonry block below the floor. Both systems tended to raise floor temperature, and the underfloor distribution also served as storage (specifically, the mass of the masonry block and the concrete floor is warmed and acts as a heat storage). A differential thermostat was used to control air flow through the roof collectors, operating whenever collector temperature exceeds floor temperature by 15°F.

Results last winter indicated a 4°F floor temperature elevation when compared to a similar unheated building (Laabs, 1978). The value of 4°F, the economics, and system improvements are still under consideration.

HEATING VENTILATING AIR FOR FARROWING HOUSES, KANSAS STATE UNIVERSITY

The system developed and demonstrated consisted of a combined collector-storage system for use of solar energy to preheat ventilating air (Spillman, 1976). The solar collector-storage unit consisted of a 16" thick masonry wall, facing south, with two transparent plastic covers. The 6"x8"x16" solid masonry blocks were stacked (no mortar), and normal spacing (1/4"-3/8") was left between the ends of adjacent blocks. The outer surface of the stacked blocks was painted black, and the plastic covers were spaced to provide for air flow between the covers and between the inside cover and the stacked blocks. Air flowed through the collector (between the plastic covers) then flowed through the block wall via the vertical gaps between blocks. A plenum chamber was arranged on the inside of the block wall, and a ventilating fan in the wall of the plenum chamber drew the air through the system and exhausted warm air into the farrowing house.

The air-flow path, for better clarification, was as follows: outside air entered between the two plastic covers (air was heated), then moved between the inside cover and the block wall (air heating continued), then through the vertical gaps in the wall (some heat in air transferred to storage in the wall) to the plenum, and finally through the ventilating fan to the farrowing house. If the air entering the wall was below wall temperature, then the air gained heat from storage (the wall), and the animal environmental temperature continued to be improved.

The collector-storage system can be added to the south wall of an existing building, or it can be built as the south wall of a new building. The researchers have been pleased, and in fact, several units have now been constructed in Kansas. An animal shelters solar energy project is now underway to evaluate this type solar system under different climatic conditions. The new project is near the Purdue campus in Indiana.

Spillman and Hines (1978) estimate that energy collected and used effectively for farrowing houses maintained at temperatures from 65°F to 80°F will be equivalent to that of burning 1 1/4 to 2 gallons of LP gas per square foot of collector per heating season. They also estimate that 50% of the solar energy arriving at the collector covers will be added to the ventilating air entering the building. About 2/3 of this energy will be added to the ventilating air during the hours between 8 p.m. and 8 a.m. (obviously the storage concept is working). Some heat may be carried through to a cloudy day but a backup furnace is provided.

SOLAR ASSISTED HEAT PUMP, VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

A water-to-air heat pump was utilized in this project to heat a portable nursery building (8'x16') in which the pigs were managed in a three-deck cage arrangement. Commercial flat plate collectors were used, and the storage component was a small water impoundment (550 gallons) with installation on the sides and floating polyurethane boards on the panel surface. This storage arrangement was an investigation of a storage means that would reduce the cost of energy storage. The heat pump served to extract heat from the fluid stored in the pond, thereby heating the ventilating air for the nursery. The total system demonstrated was small, housing 36 pigs (10 lbs. to 38 lbs. in 34 days), but the effort did demonstrate that the heat pump and small pond can be combined in a successful sytem (Vaughan, et al., 1978).

Use of larger ponds, or even waste lagoons, was considered, and some merit found. The limiting factor is that most heat pumps, because of water freezing, have safety switches which stop operation at about 35°F. Using anti-freeze in the fluids, and heat pumps that are operatable below 35°F, it is proposed that low cost heat could be obtained from ponds or lagoons when solar energy was not available, using the same equipment used for the solar energy conversion, and at a cost compatable with other energy sources. Plans continue for further investigation.

SOLAR ENERGY-INTENSIFIER-THERMAL ENERGY STORAGE SYSTEM, SOUTH DAKOTA STATE UNIVERSITY

An intensifier will be incorporated with this collection system (Hellickson, 1978). The intensifier has a purpose similar to that when a small magnifying glass is used to create a small, bright, and quite warm spot of sunlight on your hand. In this case, the intensifier is focused on a flat plate collector. The flat plate arrangement also captures some direct sunlight. The collector is further arranged as a two sided collector--two flat collector surfaces tilted together to give a cross sectional profile of an inverted "V". Inside of this cross section is located native stone for energy storage. Air moves horizontally through the collectors, then through the triangular section over the rocks and then the warm air is available for use.

This design is intended for multi-purpose application, such as grain drying or heating ventilating air for a swine finishing floor. The project was initiated in July 1978, so results are not available. The features of using an intensifier and the multi-applications will be watched with interest.

OBSERVATIONS

Many more systems with many more variations have been under the livestock housing programs and by many other innovators. From all of these efforts, progress is

being made, and gradually guidelines are being established. Listed below are a few of these--some are rather obvious and some are certainly not absolutes--but they do represent progress with solar systems for livestock shelters.

1. Do not attempt to store heat in the ground.
2. Insulate carefully any ducts or piping in contact with the ground.
3. Utilize low-grade heat (or low temperatures) that flat plate collectors can best provide.
4. Animal housing requires large volumes of ventilation--this constitutes the greatest heat requirement.
5. Animal housing ventilating air is usually fouled with dust, corrosive gases, etc. Design handling equipment accordingly.
6. Solar systems utilizing liquids are subject to corrosion problems--treat the liquid using best known technology.
7. Consider the inclusion of collector surfaces in the surfaces of the structure.
8. Any heat transfer device will cause a loss of efficiency--some must be used, but limit the number.
9. Keep the system simple; this just might prove to be an economic mandate.
10. Heating floors where litter is involved (poultry) may prove unsatisfactory.
11. Practice the best heat conservation techniques available.

CONCLUSIONS

Perhaps the foremost conclusion at this time with regard to solar energy for livestock shelters is simply that it is too early to make any conclusions. With this plainly in mind, let me close with these summary statements.

1. Economic feasibility is strongly dependent on fuel costs--most systems are now only marginally feasible.

2. Much knowledge and experience is being gained--a fundamental purpose of the DOE Pass-Through Livestock Shelters program.

3. Energy non-availability knocks out economic concerns immediately when and if such occurs. A storagehouse of knowledge and experience in the applications of solar energy to agriculture will hopefully save the day.

4. Individuals interested in solar applications now should be advised properly--and if they elect to move forward, excellent! Such leadership will continue to expand our storehouse of knowledge and experience.

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Future Energy Costs

OTTO C. DOERING, III

Today no one really has the capacity to predict future energy costs with a high degree of accuracy, and the crystal ball that I possess is no better or worse than anyone elses. The Department of Energy and a number of other institutions maintain rather complex forecasting models to look ahead at future energy prices. These forecasts are based upon definite scenarios of events that act to influence energy costs in one direction or another. However, the forecasts from these models can be upset by unforeseen changes in the scenario. I have recently been working with one such set of projections which has been completely upset by the passage of the natural gas portion of the President's energy program. It is fortunate that not too much was decided on the basis of this projection. As a result of the very great problems of forecasting energy prices, it may be much more useful to point out trends and identify indicators that should be watched to allow you to make intelligent decisions rather than fill you with numbers which may prove meaningless later on. In other words, I would rather that you were equipped with a good barometer than given a precise-sounding 90 day forecast of the coming weather. In addition, once you have some idea about the forces that shape energy prices, then it will be important to put energy use into the context of your type of business operation.

OUTLOOK FOR MAJOR FUELS

One of the major arguments is whether there is any energy problem at all. Some say that energy resources are being hidden from us by major oil companies or the government. Others claim that the situation is so desperate that we will run out of petroleum and natural gas completely before the end of this century. As a guess, the truth probably lies somewhere in between. It should be logical to assume that in this country we have already discovered most of our easily discoverable oil and natural gas. For example; the shallow oil deposits in Oklahoma have been thoroughly tapped. Now we will have to go deeper in other areas and get involved in much more expensive search and recovery operations like offshore drilling off of the East Coast. There is general concurrence among petroleum geologists that there is a limited amount of oil and gas on the earth's crust, and that we have already located and largely exploited about one-half of these resources that are recoverable under current technology. The resources are finite, and we have already used some proportion of them.

Specifically with respect to petroleum, we are going to become increasingly dependent upon foreign oil unless we are forced to make some major changes in the way we consume petroleum or unless we are willing to pay the currently higher costs of utilizing substitutes. The major oil reserves of the world are located outside our

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borders. At the time of the Arab oil embargo we were importing about one-third of our oil - now we are importing one-half of it. Secretary Schlessenger indicated that in 1985 we would be importing ten million barrels of oil a day against our current rate of about eight million. If we were to continue on the current course, that projection could be optimistically low.

There has not actually been enough of a price increase in petroleum to discourage us from using increasing amounts. Certainly the price of gasoline and diesel fuel has gone up. Everywhere we hear people complaining about the high cost of gasoline, heating fuel, petrochemicals and all the other petroleum based products. However, we also hear people complaining about the high cost of food, housing, automobiles, medical care and almost everything else that we purchase. If we compare the price of gasoline with the price of other goods that we buy, there is not much difference. The costs of many other items have increased as much or more as the cost of petroleum products. Politicians tell economists that the free market is not working. The price of gasoline has gone from about 30¢ a gallon before the Arab oil embargo to more than 60¢ a gallon today; yet gasoline consumption is as high as ever. Economists have not been very adept at pointing out to the politician that the absolute amount of cents or dollars a consumer pays for a good is not the deciding factor in consumer choice. The consumer decision is based upon the price of a good relative to other goods. The relationship between petroleum products and other goods has remained somewhat the same over time (after the embargo price shock) as the prices of other goods have increased and caught up to petroleum. Even though it may appear to take a bigger portion of your operating budget, the price increase in petroleum products is at least partially illusory.

We have also had an implicit discount in the price of our imported oil over the last 18 months to two years. The sharp fall in the value of the dollar against gold and other hard currencies gives us this discount as long as Arab nations continue to be willing to accept payment in dollars. The Arab nations have not increased the dollar price of oil anywhere near as fast as the value of the dollar has been falling. In terms of the buying power of the dollar on world markets, we are probably getting our imported oil for 20% or so less today than we were a year or two ago. This is of great concern to the Arabs, as you might guess. However, at the moment we have an excess supply of oil around the world. This results from exploration and drilling activity that took place at the time of the Arab oil embargo and immediately thereafter. This product is coming on stream right now, from Alaska, the North Sea, Nigeria, Venezuela and other places. Until demand increases or until this excess product is used up (and Secretary Schlessenger tells us that it will be used up by the mid 1980's) it will be difficult for the OPEC countries to enforce the price increases that would be necessary to restore the buying power of their dollar oil receipts to equal where it was several years ago.

Our domestic demand for petroleum also continues to increase because the American consumer is not paying a price as high as the world price for oil. The average price paid to our domestic producers is far below the price that we pay to the Arabs for imported oil. If half of our oil is imported and half is domestic, then the price we actually pay is about halfway between the $8 a barrel paid to domestic producers and the $14 a barrel that we pay for foreign oil. If our domestic production is fixed or declining, every additional barrel of oil we use has to be purchased at the world price of $14. Yet, the consumer pays about $11 for additional oil that is consumed.

In almost all other countries of the world consumers face much higher petroleum prices than we do. This is especially true in European countries where gasoline taxes have historically been a major source of government revenue. Even the Soviet Union has recently revised its pricing policy and drastically increased the price of petroleum products to consumers on the basis of the higher cost of newly discovered oil as compared with that from older producing wells that are going dry. The major determinant of future petroleum products is going to be our own government's attitude towards domestic price policy. This will depend upon whether we are willing to continue to give an indirect subsidy to the consumer by keeping petroleum prices down in contrast to the actions by other nations which increase the price of petroleum to their consumers at levels well above current production costs.

Natural gas is in somewhat the same position as petroleum in terms of its availability. Many years ago it was considered almost a waste product, something one found on the way to oil and burned off so that the oil could be exploited. In fact, natural gas is our most valuable fuel. It is an almost completely clean fuel that is easily transportable. In addition, it is a superior petrochemical feedstock. In spite of its advantages over other fossil fuels, we have regulated its price so that it costs less to use than petroleum. This is one reason the use of this fuel grew so rapidly in the late 1950's and through the 1960's. The recently passed natural gas compromise will tend to bring the price of this fuel closer to the price of petroleum, assuming that we continue our cheap petroleum policy. If we adopt a petroleum policy more similar to that of other countries, then natural gas will remain at bargain prices and government will have to ration the available supplies in a more strict and direct fashion than they have been doing over the last several years. There are some important provisions in the new bill that relate to agriculture; however, we will leave the discussion of these until later and put them in the context of your operation.

Most people think of LP-gas as a petroleum product, and its origin is as a by-product of the petroleum refining industry. This is not the case today. Roughly two-thirds of the LP-gas that we use comes from natural gas. The propane and butane are mixed with natural gas as it comes from the ground and are separated out and sold separately. Thus, the availability of LP-gas is very dependent upon the availability of natural gas, though government regulations have tended to tie its price more to that of petroleum than to natural gas.

Over the past we have imported modest amounts of LP-gas and even more modest amounts of natural gas. The Federal government recently refused to approve a long term agreement with Mexico that would have led to the importation of Mexican natural gas at a price of $2.60 a thousand cubic feet. At the same time agreements are being made and approved by DOE to bring in Liquefied Natural Gas at prices that may range from $4 to $6 a thousand cubic feet. Some part of this decision may be attributable to an unwillingness to have large volumes of natural gas come in from Mexico at a price higher than we were willing to let our own producers receive. In contrast, while the LNG prices are higher, the volumes will be much lower and the total price effect may well not be as great. It is very possible that in a year or two the Mexican contract that has been turned down will appear to have been a tremendous bargain.

The price of electricity is going to continue to go up, probably as fast as the increase in petroleum prices, and faster if we continue a cheap petroleum policy. This

is not only because of the increased cost of coal or nuclear fuel, but also because we are replacing old facilities that were built 20 or 30 years ago with facilities that cost several times more on a per megawat basis. If this increased capital requirement is compounded by the increased cost of capital, there is no way we can conceive of having anything other than rapidly increasing electricity prices. Some North Central states are projecting over ten percent annual increases in electricity rates over the next five to ten years.

WHAT DOES THIS ALL MEAN FOR AGRICULTURE?

The real concerns for agricultural producers are availability and relative prices. Availability is important because we deal with a perishable product subject to spoilage and the whims of weather. Agriculture is one of the few major sectors of the economy that operates under such conditions. Not only is it essential to the production of the product that we have this energy, but it is also essential that the energy be available when it is needed and in the quantities needed. A manufacturing firm can shut down the assembly line and in most cases only suffer a loss based on what they then will not be able to produce. Once the farmer has set the biological process in motion at planting, the lack of an adequate or timely energy input can result in a loss of the total product and all the inputs expended up to the point of the energy shortage.

Generally, the Federal emergency allocation rules do recognize this need for the agricultural sector. The problem is one of constantly defining and redefining the essential components of the food system. It is only natural that everyone believes that they should be first priority. There is also some logic in a rather extensive definition of critical agricultural needs. There is no sense having the fuel to produce food if the fuel is not available to transport it, process it and market it to the consumer. Yet, when all the activities of the food chain are added together they account for 16 to 18 percent of the total energy used in this country. As a result there has been constant negotiation and argument as these rules are written and revised. It is essential to agriculture that the essential activities be covered in the priority categories. It is also essential that good faith be demonstrated by not trying to include non-essential activities in such categories.

The new natural gas legislation has special provisions with respect to agricultural usage of natural gas. Agricultural uses, and these are defined rather broadly, are to be protected from curtailment for "essential agricultural use" (Section 401). It also appears that the essential agricultural uses may have price protection as well, so that natural gas used for essential agricultural purposes will not have price increases as great as will occur for other users (Section 206). While the curtailment provision has real merit in terms of protecting the public against sudden disruptions in the food supply, there are aspects of the pricing provision that may not be in the best long term interests of agriculture. There are several reasons for this.

One rationale for the price protection is that the administration does not want to do anything that might result in an increase in the cost of food. Yet, energy is a relatively small component in the cost of producing, processing or marketing food as can be seen on the following page:

Table 1. Value of the Direct Energy Input Compared with the Value of Product

Stage of Use	Value of Product	Value of Energy Input	Energy Input as Percentage of Product
	----Billion Dollars----		
Production	90.8	4.5	5
Processing	151.7	1.4	1
Marketing	144	4.7	3
Home Preparation	145.3	10.3	7
Away From Home	67	8.1	12

There is no way that increased energy prices would have anything like the effect on consumer food prices that increased labor costs might have.

There is another more important price protection factor related to the health of the agricultural industry. As energy prices increase over time, these price increases should stimulate the development and adoption of new technology which is more energy efficient. In addition, we may find that we can begin to make some small substitutions of other inputs for energy. While I do not believe we are going to see anything like large substitutions of resources like labor for energy using mechanization, we may well see things like the substitution of increased management ability and time for energy as it becomes more expensive. If the natural gas use in agriculture is shielded from price increases until deregulation in 1985, then the agricultural users of this fuel will have little incentive to improve the efficiency of their operation. It looks as though the users covered by the act may include everything from fertilizer to irrigation. Such protection from the real world cannot last forever. It would certainly end with the lifting of price controls in 1985 or shortly thereafter. I believe that agriculture needs the price incentives to force us to utilize our most valuable energy resource as wisely as possible. I would prefer to make adjustments over time and have the gradual economic stimulus to do so. The price provisions of the bill may save us a few pennies now, but I am afraid that this will be at the cost of dislocation later on when we are hauled into the real world by the rest of society who will be unwilling to continuously shield our sector. Those of us in the Land Grant Institutions will be unable to justify work on alternative energy sources and new technologies if natural gas prices are kept low for agriculture. We will also be unable to convince you to adopt a new technology if the payback is negative or only positive after 30 years.

WHAT DOES THIS MEAN FOR LIVESTOCK PRODUCTION DECISIONS?

I hope that what I have said so far gives you more of a context for looking at your own energy related decisions. In addition, I need to try and give you some concrete guidelines that relate directly to your industry.

First, as with other sectors of agriculture, your direct energy consumption is a very small proportion of your total costs and an even smaller proportion of the total value of your product. The USDA cost of production figures for the North

Central Region indicate that all fuels, lubricating oils and electricity amount to five percent of the cash costs in farrow to finish operations. In Indiana, heating fuel accounts for two percent of the total cash costs. In Minnesota, with much higher heating costs, it runs about three percent. There is no way that I can justify your turning your operation upside down to save some proportion of the five percent of your total costs that direct energy inputs represent.

Indirect energy use is much greater. If we were to total up the energy that went into the production of your feed, into the production of your machinery and into the production of your other facilities this indirect energy cost would probably be much greater than your direct energy costs. However, you only have indirect control over the energy used in these items. You can only influence their production through your decisions to buy or use one item of equipment or machinery over another. Insofar as items you buy have a high proportion of their own cost based on high energy costs, then you may try and substitute a different item of lower cost. What is important is that the relatively small energy costs you can control directly should not become the sole focus of major production decisions.

Second, the timing of economic and management decisions is critical to how important energy criteria can be. If you constructed a farrow to finish hog enterprise just prior to the Arab oil embargo, there is no way anyone at Purdue or Illinois is going to recommend to you that you tear down all these facilities and replace them with more energy efficient ones. If you are in the process of expanding, or planning new replacement facilities, then you are foolish if you do not consider energy costs as a factor in the design and management of this new facility. In the case of older existing facilities there probably are things that you can do to improve energy efficiency , but the modification process is often more expensive than being able to incorporate new ideas into a structure under construction. Yet both may be real money and energy savers.

Third, if you can afford it, as an economist I would urge you to make uneconomic decisions in the expectation of future payback. I don't want you to get out on a limb, but there are times that an uneconomic decision today can pay very real future benefits. As an example; several years ago I added six inches of insulation to the 3½" already in my attic. I heat with natural gas, and the payback for this insulation was more than ten years while the average American changes his dwelling every five to six years. This was an uneconomic decision for me to make, but I was something of an energy nut. Today, Indiana Gas, in its munificence, has increased natural gas prices to the point where my payback will only take a few years. The lesson is that energy prices will continue to go up, and may well increase at a faster rate than expected if our government does not maintain its cheap fuels policy. Do not be afraid of long payback periods, especially for investment in technology that is well known and where the results are reasonably assured. The payback period may well shorten considerably. This does not say that you should invest in very expensive new technology where returns are unknown and base this on a belief that energy price increases will bail you out. A safer approach is to get your neighbor to invest in this type of activity and then see how he does before you try it.

Fourth, you are usually using energy in your operation today for very sound reasons. Some of the use of energy represents risk insurance and some of it saves human time that is much more valuable in other uses. The automated processes that require energy may well be worth it in terms of making an important operation or activity possible given the limited time to pay attention to so many activities. It is

seldom worthwhile to change an operation to save energy when the trade-off for that energy saving is increased risk or increased manual operation of formerly automated systems. These trade-offs must be considered explicitly before a decision is made to save energy.

Fifth, given a range of activities and processes in your operation that consume energy, start investigating those that are large users of energy first. The important savings come from improving energy efficiency in uses such as space heating and ventilating which are large energy users to begin with. Management time in assessing alternatives may be almost equal whether you are going after large savings or small. It is certainly worthwhile to go after the large ones first.

Finally, any agricultural operation is a highly complex and fully integrated system. Make sure that you take the extra time to also analyze any energy saving activities in the context of your total operation. For example; there would be no sense making an energy saving that resulted in decreased feed efficiency which had a greater cost than the energy saved. Conversely, you might find something that saves only a little bit of direct energy use but makes an improvement to feed efficiency as well. There are also changes that require more energy, but manage to improve production even more. Your concern should be energy efficiency per unit of output, not the absolute amount of energy going into the system.

None of what we do is in a vacuum. Our energy prices are going to be set for us on the basis of national resource use and equity considerations that are not based on an understanding of agricultural production. We do not really expect that there are going to be revolutionary breakthroughs in technology that will "solve" energy problems. Energy supplies as we know them in the form of fossil fuels are finite, and it will be several decades before renewable resources begin to replace fossil fuels in any significant way. There are opportunities and complementarities that we can identify. In livestock operations these range from increasing the efficiency of the housing unit to better utilization of manure as fertilizer where the animal operation is also part of a cropping operation. However, the operator is in the best position to make the ultimate decision. Those of us who are supposed to be assisting you cannot give you an accurate 90 day forecast. The best we can do is help you find a good barometer and give you the first lesson in its use.

Effects of Modified Housing Environments During Winter on the Performance of Growing-Finishing Pigs

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INTRODUCTION

HOUSING FOR INTENSIVE PRODUCTION OF SWINE IS DESIGNED TO PROVIDE AN ENVIRONMENT CONducive to efficient animal production. In many geographical areas, the same facility must thus be suited for use during alternately very hot and very cold seasons. And the degree of environmental control exercised is usually determined by the cost: benefit ratio. In the cold weather growing-finishing pigs in heated buildings perform more efficiently than pigs in unheated buildings (Jensen et al., 1969; Wahlstrom et al., 1971). In open-front buildings pen modifications with straw bedding, zone heat or other protective arrangements have resulted in increased efficiency of animal performance (Jones and Hinkle, 1973; Pohl and Fritschen, 1977).

This study was conducted (1) to evaluate effects of various pen sleeping area modifications--wooden overlay, wooden hover, electric radiant heat, in-floor electric heat--in a modified open-front (MOF) building and (2) to compare a MOF and an enclosed environmentally regulated building for growing-finishing pigs in the winter season.

EXPERIMENTAL PROCEDURES

Data was collected over a three-winter period in studies in a modified open-front, south exposure building (MOF) and an enclosed building (EB). The MOF had steel side walls and roof and partially slotted concrete floor pens 2.4 m x 6 m. There were 5 cm of batt insulation in the roof. Plywood panels hinged at the top could be manually adjusted to close the exposed side during severe cold weather. The EB was of wood frame, mechanically ventilated, and had partially slotted concrete floor pens 2.4 m x 4.8 m.

Pigs within each replicate were formed into outcome groups on the basis of weight and sex and individual pigs within outcome groups were randomly assigned to treatment group. A fortified corn:soybean meal diet was fed ad libitum. It contained 16% crude protein until the pigs averaged 55 kg in weight, then 14% crude protein to 90 kg.

Experiment I. This was designed to evaluate the effects of radiant or floor supplemental heat for growing-finishing pigs in the MOF building. Supplemental heat was supplied by either an electric radiant heater[1] suspended about 100 cm above the pen sleeping area or by an electric heat mat imbedded in concrete with 2.5 cm of concrete above the mat. The radiant heaters were regulated with thermostat-timer or voltage phase controller. Each pen floor mat was controlled by a thermostat in the concrete. A wooden overlay (2.4 m x 1.2 m) was used in the sleeping area in the unheated control

[1] Quartz tubes or lamps varying from 1200 to 3200 watt capacity proved satisfactory.

pens during the first two weeks of the experiment. Three replications were completed during three winter seasons. Average initial weight for each of the three replicates was 25, 29 and 28 kg , respectively.

Experiment II. This was conducted to compare the effects of a wooden overlay, a wooden hover, an overlay and hover, radiant heat and floor heat in the sleeping area of the pen. The wooden overlay and hovers were 2.4 m x 1.2 m plywood panels. The hover was located 75 cm above the sleeping area. There were three replications over two winter seasons. Average replicate initial weights were 22, 37 and 20 kg , respectively.

Experiment III. This experiment was designed to (1) compare performance in the MOF building and the EB building during winter season and (2) evaluate the effect of initial weight on performance. In the MOF building pen modifications were wooden overlay, radiant heat or floor heat in the sleeping areas. In the EB, a thermostatically controlled space heater maintained a 15 C ambient temperature. Pigs were formed into outcome groups of four based on weight and sex. They were then categorized by weight so that there were two replicates averaging 39 kg and two replicates averaging 28 kg. Pigs within outcome groups were randomly assigned to pen treatment in the two buildings.

RESULTS AND DISCUSSION

Experiment I. Average treatment values for the main comparisons in the MOF building are shown in table 1. Although there were significant differences among seasons there were no season x treatment interactions. During the first 14 days, pigs provided with either overhead radiant or in-floor electric heat in the pen sleeping area gained faster ($P < .05$) and had better gain/feed ($P < .05$) than the pigs with no supplemental heat. Feed intake was nonsignificantly lower by pigs with no supplemental heat than by those with supplemental heat. During the total 42-day period only gain/feed was significantly ($P < .05$) affected by treatment. From day 14 to day 42, the pigs were of heavier weight and less stressed by the cold, and the control pigs showed some apparent compensatory response in feed intake and rate of gain.

Average outside and inside ambient temperatures recorded are shown in table 2. The inside temperature of a 5.5° C average at 10:00 a.m. daily is well below the reported critical temperature (above 26° C) for the 30-kg pig (Mount, 1975).

Experiment II. The results obtained during two winter seasons (3 comparisons) are shown in table 3. As in Experiment I there were significant ($P < .01$) differences among seasons, but no season x treatment interaction, thus only treatment means are shown.

During the first 14 days rate of gain of pigs in the control, hover and overlay-plus-hover treatments in the MOF were slower ($P < .05$) than for the other treatments. Feed intake did not differ, and gain/feed was lowest ($P < .05$) for the control and hover treatments. For the total 56-day period, control pigs gained slower ($P < .05$) than those in the other treatments. Fastest gain was realized by pigs with floor-heat. Average daily feed did not differ significantly, but gain/feed differed ($P < .05$) among the treatments, with lowest value with the control and highest for the floor-heat.

Experiment III. Pigs in the MOF responded (ADG and G/F, $P<.05$) to both radiant and floor-heat during the first 14 days (table 4). Pigs in the EB gained faster ($P<.05$) and more efficiently ($P<.05$) than the pigs in any of the MOF pens. For the entire 28-day period, pigs with radiant heat in the MOF and the pigs in the EB gained faster ($P<.05$) than the controls and floor-heat pigs in the MOF. Gain/feed was higher ($P<.05$) in the EB than in the control pens in the MOF.

During both the 14-day and 28-day periods the replicate of pigs with higher average initial weight gained faster ($P<.05$ and $P<.01$) than the replicate of lighter weight pigs. During the 28-day period, they consumed more ($P<.01$) feed. There was no interaction between initial weight and environmental treatment. Table 5 shows the temperatures during this period of severe cold.

Behavioral responses to cold by the control pigs were similar to those reported by Mount (1960), Fuller (1965) and Sugahara et al. (1970). Marked shivering occurred soon after exposure to the cold but diminished as the animals increased in body weight. Hair coats were longer and denser than on the heat-supplemented pigs. An apparent acclimatization developed during the first 14 to 28 days of exposure and this was in keeping with Sorenson's (1962) conclusion that a 3- to 4-week period was required for 40-kg pigs to adjust to a cold environment.

A possible additional evidence of physiological stress of cold was that nine of the 330 pigs without supplemental heat in the MOF developed an anal prolapse. None of the 588 pigs in heat-supplemented areas evidenced such. The prolapse usually occurred within the first 14 days (table 6).

Results agree in general with those reported by Jones and Hinkle (1973) and Pohl and Fritschen (1977). The percent difference in the performance values between the control pigs and those with either overhead radiant or in-floor electric heat are shown in table 7. The pooled comparisons for the first 14-day periods show that gain was increased about 23% ($P<.01$) and gain/feed about 21% ($P<.05$) by providing supplemental heat. For the total period, average gain and gain/feed were increased 14% ($<.05$) and 12%, respectively. However, feed intake was not significantly affected by environmental modification. This disagrees with previous results (Jensen et al., 1969; and Wahlstrom et al., 1971) which showed that cold stress stimulated feed intake in growing pigs, presumably a compensatory reaction to the extra metabolic activity needed to maintain homeostasis. The difference between our present data and the previous results likely reflects the absence or presence of straw bedding for the control pigs. In the earlier report (Jensen et al., 1969),in addition to a wooden overlay in the sleeping area,a liberal amount of straw was supplied. The protective value of this material is indicated by Sorenson (1962) who found that straw bedding for pigs confined to concrete-floored pens in a room temperature of 3° C increased rate of gain and gain/feed by 14.3 and 16.4%, respectively. And Verstegen and Van Der Hel (1974) reported that the effective critical temperature for 40-kg pigs was 11.5 to 13° C on straw bedding and 19 to 20° C on concrete slats. Under environment-controlled conditions, Verstegen et al. (1977), found that pigs from 20 to 90 kg required an average of 31.8 g of extra feed per C below thermoneutrality to maintain rate of gain on concrete slats comparable to concrete floor plus straw. Also, gain was reduced an average of 15.1 g per C below thermoneutrality.

In our experiments no bedding was used and the control pigs were observed to spend much more time huddling together to protect against the cold, and likely spent less time at the feeder than pigs with supplemental heat. Also, during the first week of

each trial the control pigs had poorer housekeeping habits and the wooden overlay was frequently wet, which would exaggerate body heat loss.

The difference in performance between the MOF control pigs and those in the heated, enclosed building (Experiment III)shows that daily gain per kg of feed consumed decreased 3.5 g per C decrease in temperature. This is the same as noted previously (Jensen et al., 1969). Daily gain, however, decreased 7 g per C decrease, whereas it decreased only 2 g in the earlier comparison when straw bedding was used.

These results emphasize the energy-cost, either feed or fuel, of production during winter seasons. And quite apart from these data but relative to total management is the associated herder comfort and convenience in the different housing units.

CONCLUSIONS

1. Pen modification to reduce cold weather stress in a modified open front (MOF) building with partially slotted concrete floors resulted in improved performance of groups of pigs having average initial weights of 27 and 39 kilograms.

2. Ambient average daily temperatures inside the MOF, recorded 10:00 a.m. daily, for Experiments I, II and III were 5.5, 2.0 and 2.5° C., respectively.

3. Rate of gain and gain/feed in each experiment were improved when either overhead radiant or floor heat was used in the sleeping area.

4. In Experiment II, a wooden overlay in the sleeping area resulted in improved gain and gain/feed, but a plywood panel suspended at 75 cm above the sleeping area did not.

5. Average feed intake was not significantly affected by pen modification.

6. Greatest treatment effect was during the first 14 days of each experiment. In subsequent periods, as pigs increased in size, lesser effects were realized.

7. Pigs in an enclosed building (15° C ambient temperature) gained faster and more efficiently than pigs in the modified pens in the MOF building.

8. Nine of 330 pigs without supplemental heat in the MOF developed an anal prolapse. None occurred in the 564 pigs in radiant or floor heat pens.

9. Using prices of $0.04 per kw hr of electricity and $0.13 per kg of feed, the amount of feed saved by pen supplemental heat in the MOF did not fully compensate for the electrical energy used.

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TABLE 1. SUMMARY OF EFFECTS OF PEN ENVIRONMENT MODIFICATION IN A MODIFIED OPEN-FRONT BUILDING ON PERFORMANCE OF GROWING-FINISHING SWINE (EXPERIMENT I)

	Supplemental heat[a]		
	None	Radiant	Floor
Day 1 to 14[b]			
Avg. daily gain, kg *	.46[c]	.56[d]	.54[d]
Avg. daily feed, kg	1.54	1.61	1.60
Gain/feed *	.299	.348	.337
Day 1 to 42			
Avg. daily gain, kg	.62	.67	.66
Avg. daily feed, kg	2.14	2.19	2.18
Gain/feed *	.290	.306	.303

[a] None - no supplemental heat, but a wooden overlay (2.4 m x 1.2 m) provided in the sleeping area. Radiant - electric radiant heater suspended about 100 cm above the sleeping area. Floor - electric heat mat imbedded in the concrete in the sleeping area.
[b] Average initial weight was 27 kilograms.
[c] Each value is an average for six groups of 11 pigs each.
[d] Each value is an average for 18 groups of 11 pigs each.
* $P < .05$.

TABLE 2. SUMMARY OF AVERAGE TEMPERATURES DURING EXPERIMENT I

	Temperature, C		
	Outside[a]		Inside
	Avg.	Range[b]	Avg.[c]
Day 1 to 14	1.0	-5.0 to 2.8	5.5 (42)[d]
Day 1 to 42	2.0	-3.0 to 6.0	7.0 (45)

[a] Information from the Illinois State Water Survey Division weather summary data, Champaign.
[b] Lowest and highest daily mean of the period.
[c] Readings were recorded at 10:00 a.m. daily. A mercury thermometer was located 45 cm above the aisle floor 75 cm from the back wall.
[d] Degrees Fahrenheit.

TABLE 3. SUMMARY OF COMPARISONS OF EFFECTS OF VARIOUS PEN ENVIRONMENT MODIFICATIONS IN A MODIFIED OPEN-FRONT BUILDING ON PERFORMANCE OF GROWING-FINISHING SWINE (EXPERIMENT II)

	Pen modification [a]					
	None	Overlay	Hover	Overlay and hover	Radiant heat	Floor heat
Day 1 to 14[b]						
Avg. daily gain, kg	.46[d]	.57[e]	.49[d]	.53[d]	.55[e]	.56[e]
Avg. daily feed, kg	1.67	1.76	1.67	1.70	1.74	1.64
Gain/feed	.270[d]	.324[e]	.293[d]	.315[e]	.316[e]	.341[e]
Day 1 to 56[c]						
Avg. daily gain, kg	.57[d]	.63[e,f]	.61[e]	.62[e,f]	.65[f,g]	.68[g]
Avg. daily feed, kg	2.07	2.14	2.10	2.17	2.15	2.17
Gain/feed	.275[d]	.294[d,e]	.290[d,e]	.287[d]	.302[e,f]	.313[f]

[a] The modification affected only the 2.4 m x 1.2 m sleeping area of the pens. Each value is an average for six pens of 10 pigs each.

[b] Average initial weight was 27 kg. Average outside temperature during the 14-day period was 0° C, range of -13 to 12 C. Inside temperature, recorded at 10:00 a.m. daily, averaged 2° C., range of -9 to 8° C.

[c] Average outside temperature was -2° C, range of -15 to 8° C. Inside temperature, recorded daily at 10:00 a.m., averaged 0, range of -11 to 10° C.

[d-g] Values on the same line with different superscripts differ significantly ($P < .05$).

TABLE 4. SUMMARY OF COMPARISON OF PERFORMANCE OF GROWING PIGS IN A MODIFIED OPEN-FRONT BUILDING AND AN ENCLOSED AND HEATED BUILDING (EXPERIMENT III)[a]

Building	Modified open-front[b]			Enclosed[c]	
Heat source	None	Radiant	Floor	Space heater	
Avg. initial wt., kg[d]					Avg.
Replicate 1	39	39	39	39	39
Replicate 2	28	28	28	27	28
Avg.	33	33	33	33	
Day 1 to 14					
Avg. daily gain, kg					
Replicate 1	.54	.74	.64	.83	.69*
Replicate 2	.42	.52	.63	.67	.56
Avg.	.48[e]	.63[f]	.63[f]	.75[g]	
Avg. daily feed, kg					
Replicate 1	2.16	2.20	1.99	1.89	2.06
Replicate 2	1.51	1.67	1.64	1.65	1.62
Avg.	1.83	1.94	1.82	1.77	
Gain/feed					
Replicate 1	.250	.335	.322	.439	.336
Replicate 2	.278	.311	.384	.406	.345
Avg.	.264[e]	.323[f]	.353[f]	.422[g]	
Day 1 to 28					
Avg. daily gain, kg					
Replicate 1	.62	.74	.69	.79	.71**
Replicate 2	.41	.52	.49	.60	.50
Avg.	.51[e]	.63[f]	.59[e]	.69[f]	
Avg. daily feed, kg					
Replicate 1	2.21	2.26	2.14	2.19	2.20**
Replicate 2	1.74	1.64	1.72	1.82	1.73
Avg.	1.97	1.95	1.93	2.00	
Gain/feed					
Replicate 1	.283	.329	.320	.361	.323
Replicate 2	.235	.318	.287	.333	.293
Avg.	.259[e]	.323[e,f]	.303[e,f]	.347[f]	

[a] January 4 to 31, 1978.
[b] See footnote a, table 1.
[c] Ambient temperature maintained at 21° C.
[d] Each value is an average for 2 pens of 12 pigs each.
[e,f,g] Means on the same line with different superscripts differ significantly ($P < .05$).
* $P < .05$.
** $P < .01$.

TABLE 5. SUMMARY OF WEEKLY AVERAGE TEMPERATURES AND RANGE OF TEMPERATURES IN THE MODIFIED OPEN-FRONT BUILDING IN EXPERIMENT III

Days of experiment	Temperature, C			
	Outside[a]		Inside[b]	
	Avg.[c]	Range[d]	Avg.[e]	Range[f]
1 to 7	-9	-13 to -7	-3 (27)[g]	-9 to 0
8 to 14	-8	-12 to -3	-2 (28)	-7 to 4
15 to 21	-12	-17 to -8	-4 (25)	-12 to 3
22 to 28	-10	-15 to -6	-7 (19)	-13 to 1

[a] Information from the Illinois State Water Survey Division - weather summary data, Champaign.
[b] See footnote c, table 2.
[c] Average of daily means.
[d] Lowest and highest daily mean.
[e] Average of 10:00 a.m. readings.
[f] Lowest and highest daily 10:00 a.m. reading.
[g] Degrees Fahrenheit.

TABLE 6. FREQUENCY OF OCCURRENCE OF ANAL PROLAPSE DURING EXPERIMENTS I, II AND III

Experiment	Pen modification in the MOF						
	None	Overlay	Hover	Overlay and hover	Radiant heat	Floor heat	Heated building
I	-	0[a]/66[b]	-	-	0/198	0/198	-
II	3/60	1/60	2/60	1/60	0/60	0/60	-
III	-	2/24	-	-	0/24	0/24	0/24

[a] Number of animals that developed an anal prolapse.
[b] Number of animals on treatment.

TABLE 7. RELATIVE PERFORMANCE RESPONSE (%) OF GROWING-FINISHING PIGS TO RADIANT OR FLOOR HEAT IN PENS IN A MODIFIED OPEN-FRONT BUILDING[a]

	Control[b]	Supplemental heat	
		Radiant	Floor
	%	%	%
Day 1 to 14			
Avg. daily gain **	100	124	123
Avg. daily feed	100	105	101
Gain/feed *	100	118	124
Total period[c]			
Avg. daily gain *	100	114	114
Avg. daily feed	100	102	102
Gain/feed	100	113	112

[a] Pooled data from Experiments I, II, III.
[b] Wooden overlay in sleeping area in Experiments I and III, no pen modification in Experiment II.
[c] Periods for the three experiments were 42, 56 and 28 days.
* $P < .05$.
** $P < .01$.

Selection and Breeding Programs for Baby Pig Survival

RODGER K. JOHNSON

THE NUMBER OF PIGS WEANED PER SOW IN THE BREEDING HERD PER YEAR IS PERHAPS THE MOST important factor determining the economic success of commercial swine production systems. This trait is often used as a benchmark of success or failure. Much is said and written about ways to improve this trait. Producers, however, have learned that it is a very complex trait.

Pigs weaned per sow per year is determined by several factors. First, we must have high conception rates. Then ovulation rate sets the upper limit to litter size at birth; consequently to get large litter size at birth, the breeding herd must be fertile and have the genetic potential for high ovulation rate. Assuming that we have females with this genetic potential, the number of pigs born will be determined by the survival rate of embryos within the uterus. And the number of pigs weaned per litter will depend on the survival rate of pigs from birth to weaning.

Ovulation rate in most breeds of swine is quite a lot higher than litter size. Research at Oklahoma found average ovulation rates were between 12.5 and 14 eggs for purebred and crossbred gilts of Duroc, Hampshire and Yorkshire breeding. From 10 to 25% of these eggs were lost by 30 days of gestation, 25 to 30% were lost by farrowing and at weaning only 50 to 65% of the eggs ovulated were represented by a pig. Consequently, increasing the survival rate of pigs, both in the embryonic stage and from birth to weaning, will significantly increase the efficiency of pork production.

FACTORS INFLUENCING PIG SURVIVAL

Environmental and management differences among farms, years and seasons of farrow are large causes of embryonic and pig death losses. Causes of death include overlay by the sow, injury, starvation, chill, gastroenterities, pneumonia, and perhaps several other diseases. These factors are primarily environmental and point out the necessity for good management.

In addition, we are concerned with genetic factors that are related to survival rate of pigs. Table 1 presents the results of Oklahoma research that evaluated the influence of pig birth weight on survival rate. The average pig birth weight was 2.93 lbs. with 87.2% of the pigs weighing between two and three pounds. No pigs survived that weighed less than one lb. while 95% of the pigs weighing four lbs. and over survived to weaning.

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Table 1. Influence of Pig Birth Weight on Survival Rate from Birth to Weaning

Item	Pig birth weight, lbs				
	Below 1	1.0 to 1.9	2.0 to 2.9	3.0 to 3.9	4.0 to 4.9
No. of Pigs	7	191	1041	1030	106
Death loss, %	100.0	60.7	19.5	9.6	3.8

Omtvedt, I.T. 1970. Okla. Agr. Exp. Sta. MP 84:83

It would seem from this that if we just selected for increased pig birth weight, we would also improve survival rate. It is not this simple, however,as pig birth weight is influenced by litter size at birth (figure 1). There is a general trend toward larger litters to have lighter pigs. The heaviest pigs were obtained in litters of four to six pigs. Survival rates were 80% or better in all pigs weighing above two pounds (table 1). Average birth weight did not drop below two pounds until litter size was greater than fifteen. Selection for large birth weight would indirectly select pigs from small litters. The result may be higher survival rate, but not necessarily more pigs weaned per sow per year.

The relationship between litter size and percent surviving to weaning was evaluated from 9,299 litters farrowed at experiment stations in eight midwestern states. Maximum survival rate occurred in litters of eight to nine pigs at birth (figure 2). Does this mean that litter size at weaning is maximum when litter size at birth is 8 to 9 pigs? Even though percent survival decreases as litter size increases, up to a point larger litters at birth are expected to be larger at weaning. On the average, litters of 8,10 and 12 pigs at birth had about 6.1, 7.6 and 8.9 pigs at weaning, respectively. Litter size at weaning increased until litter size at birth averaged about 16 pigs even though percent surviving to weaning decreased as litter size at birth increased. Litter size at birth does have a detrimental effect on pig survival rate; however, large litters at birth are necessary if we expect large litters at weaning.

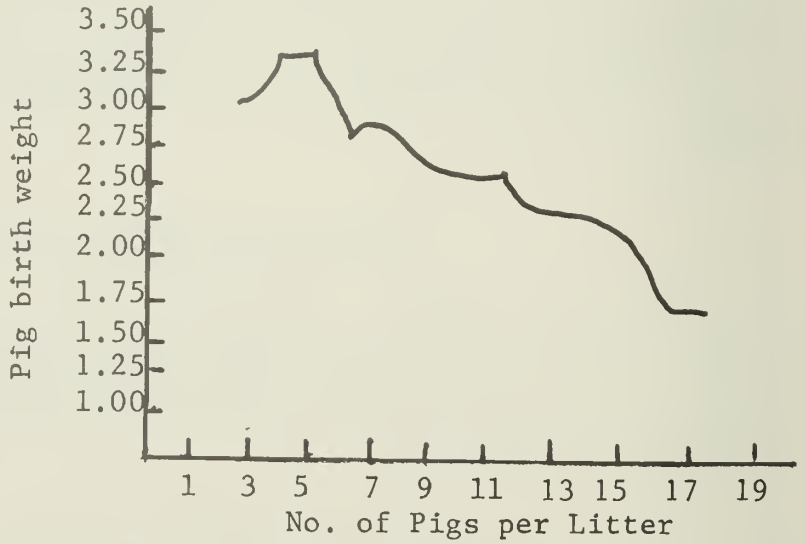

Figure 1. Relationship Between Litter Size and Average Pig Birth Weight Among Gilt Litters. Omtvedt, I.T., 1970. Okla. Agr. Exp. Sta. MP 84:83

Figure2. Relationship Between Litter Size and Percent Surviving to Weaning.
Vereskin et al., 1973. J. Anim. Sci. 36:821.

Another genetic factor that is detrimental to pig survival rate is inbreeding. Inbred litters are expected to be smaller at weaning simply because inbred pigs have a lower survival rate than non-inbred pigs. Also, pigs raised by inbred dams, on the average, have a lower survival rate than pigs raised by non-inbred dams. The mating of related individuals is not recommended for commercial production and should be used with caution by purebred breeders.

Fortunately, crossbreeding has the opposite effect of inbreeding and results in increased vigor in the pigs and higher pig survival rates. This is discussed in detail below.

SELECTION PROGRAMS

Since only pigs that survive reproduce, there is some natural selection for baby pig survival. Any additional selection must be made by indirect selection for other traits. For example if a pig is born and weaned in a large litter, this must be a litter with relatively high embryonic survival rate as well as high baby pig survival rate. Selection for litter size then will indirectly select for baby pig survival.

A management practice that can effectively increase baby pig survival and that will aid in selecting for litter size is to transfer pigs among litters at birth to standardize the size of litters being nursed by the sows. This will increase the chances for survival of pigs born in very large litters.

There is also experimental evidence that gilts born in large litters but reared in smaller litters are better able to express their genetic potential for litter size than if they were raised in large litters. Work done at North Carolina (table 2) compared the reproductive performance of gilts that were reared in small (six pigs) and large (14 pigs). Litter sizes were formed by realloting pigs between dams at birth. After breeding, about half of the gilts were slaughtered 30 days post breeding to evaluate embryo survival rate and the remainder were farrowed.

Table 2. Effect of Size of Litter in Which a Gilt is Reared on Her Subsequent Reproductive Performance

Trait	Size of litter as reared: Six No.	Six Avg.	Fourteen No.	Fourteen Avg.	Difference 6-14
Ovulation rate	56	13.0	57	12.0	1.0
No. of embryos	56	11.0	57	9.9	1.2
No. born	59	9.2	61	8.3	.9

Nelson and Robison. 1976. J. Anim. Sci. 43:71.

It does not appear that embryo survival is better in gilts reared in small litters (85.4% vs 82.5%). However, gilts reared in small litters seem better able to express their genetic potential for ovulation rate and litter size. This, plus the fact that survival of pigs is expected to be greater in litters where number of pigs have been standaridized, makes this a highly recommended management practice.

How effectively a trait can be changed by selection depends on the heritability of the trait (heritability is the percentage of the observed differences that are expected to be caused by genetic differences). The approximate heritabilities of some of the reproductive traits in swine are shown in table 3. Ovulation rate is quite highly heritable and research at Nebraska has demonstrated that ovulation rate can be effectively increased by selection. It is encouraging that the upper limit to litter size can be increased.

Table 3. Approximate Heritabilities of Certain Traits Related to Litter Size and Pig Survival

Trait	Heritability, %
No. eggs ovulated	40
Litter size born[a]	16
Pig birth weight	15
Litter size weaned	10
Litter 21 day weight	25

[a]Heritability of litter size if standardized at birth.

No direct estimates of the heritability of embryo and pig survival rate are available. The heritability of litter size born (16%) and litter size weaned (10%) however would indicate that most of the variation in survival rate is environmental or of a genetic nature that does not respond to selection. Direct selection for baby pig survival is not expected to cause very much change. However, selection of dams and pigs from dams with above average milk production should improve baby pig survival. This trait can best be measured by litter 21 day weight and fortunately has a reasonably high heritability and should respond to selection.

From the above, we see that it is essentially impossible to outline steps for directly improving baby pig survival by selection. Perhaps it can be improved with a total selection program that emphasizes several traits. In addition to litter size and baby pig survival, efficiency and composition of growth are important. Selection programs in seedstock herds should emphasize all economically important traits. The National Swine Improvement Federation has developed guidelines (avail-

able through the State Extension Service) and an index for selection that put emphasis on the litter size in which a pigs is born, the 21 day weight of the pigs raised by the individuals dam and the pigs own age and backfat at 220 pounds. Standardization of litters at birth is recommended and sows should be culled from the herd based on litter size born and the total 21 day weight of the pigs they nurse. To effectively use this program, a good record keeping system is necessary. Replacement boars and gilts then should be from large litters whose dams are good milkers and should be superior for growth rate and backfat thickness at 220 pounds. This program puts some emphasis on mothering ability that should improve pig survival. In addition improvements can be expected in litter size.

Commercial producers, however, generally can not afford the testing program and record keeping system that this program requires. Some general guidelines for commercial producers are:

1. Obtain high indexing boars from seedstock herds emphasizing all economically important traits.
2. At birth record litter size for each sow and transfer pigs to standardize litter size. Preferably males should be transferred from large to small litters so identity of gilt and dam can be maintained.
3. At weaning, identify (notch in ear, etc.) the larger gilts from the dams with large litter size born. Approximately twice as many gilts should be identified as are needed as replacements.
4. At 220 lbs. select the faster gaining, leaner gilts from those identified at weaning.
5. Cull sows with small litters at birth and those that nurse pigs that are small at 21 days.

It should be emphasized that changes in litter size and baby pig survival are not expected to be rapid. However, being persistent and staying with the program over several years should yield improvement.

CROSSBREEDING PROGRAMS

Much of the swine breeding research at Oklahoma has been an evaluation of breeds as purebreds and as crosses. Over a five year period purebreds, two-breed crosses and three-breed crosses of Durocs, Hampshires and Yorkshires have been produced. Matings were made in two phases. First, purebred boars and gilts of each breed were mated so that all combinations of purebreds and two-breed crosses were produced. Then purebred and crossbred gilts were mated to produce two-breed and three-breed cross litters. In each season, a group of gilts was randomly selected and slaughtered 30 days after breeding to evaluate ovulation rate and early embryo liveability. The remaining gilts were farrowed in crates and transferred three to five days postfarrowing with litter to a nursery facility. Litters were weaned at 42 days of age.

Table 4 presents the average litter size and pig survival for purebred and crossbred litters from phase I. There was a slight advantage for crossbred litters in the early embryo survival rate. Consequently, crossbred litters were somewhat larger than purebred litters 30 days postbreeding. The difference between cross-

breds and purebreds was the same for litter size at birth and litter size at 30 days of gestation. However, crossbred litters were .7 pigs larger at weaning than purebred litters. This was due to a 7.9% increase for crossbred pigs in survival to weaning.

Table 4. Litter size and Pig Survival for Litters From Purebred Gilts When Producing Purebred or Crossbred Litters

Breed Group[a]	No. Litters[b]	No. embryos 30-days postbreeding	Embryo survival rate, %	Litter size at birth	Litter size at weaning	Pig survival to weaning, %
DxD	25-55	11.1	81.2	8.9	5.3	58.1
HxD	22-45	11.5	80.5	9.0	6.0	66.1
YxD	29-50	10.9	77.1	10.8	7.2	68.3
HxH	28-56	8.4	69.9	8.4	5.2	59.3
DxH	27-52	9.6	78.6	8.3	6.0	72.7
YxH	29-56	9.6	79.0	8.5	6.6	78.6
YxY	19-50	11.2	84.2	10.2	7.4	72.0
DxY	18-46	11.2	82.6	10.8	8.0	73.7
HxY	15-40	11.6	81.5	9.9	6.5	66.4
Purebreds	72-161	10.2	78.4	9.2	6.0	63.1
Crossbreds	140-289	10.7	79.9	9.6	6.7	71.0
Crossbred advantage		+.5	+1.5	+.4	+.7*	+7.9*

[a] First letter represents breed of sire and second breed of gilt (D=Duroc, H-Hampshire, Y=Yorkshire).

b First column is the number of gilts slaughtered 30 days postbreeding and the second is the number of gilts farrowed.

*Significant advantage for crossbreds.

From this we see that pig survival is greater for crossbred pigs than for purebred pigs and that the crossbred advantage gets larger as the pigs get older. In addition, we see some differences in survival rate for the three breeds involved. Survival rates for litters out of Yorkshire gilts were higher than for litters out of Duroc and Hampshire gilts. This suggest that maximum pig survival can be attained through crossing of breeds that are superior for pig survival. It should be pointed out that the increased survival rate of crossbred pigs does not appear to be caused by an increase in birth weights for purebreds and crossbreds were essentially equal.

The comparison of crossbred and purebred dams is presented in table 5. A big advantage exists for crossbred sows for pig survival and consequently for litter size. Three-breed cross litters from crossbred gilts had a 6.5% advantage for embryo survival to 30 days of gestation and a 4.9% advantage for pig survival from

birth to weaning. The crossbred sows had the greatest effect on pig survival early in gestation and from birth to weaning. Again the advantage of crossbred sows becomes increasingly larger as the pigs get older. Maximum advantage was realized by 21 days of age.

The advantage early in gestation may be due to larger embryos as three-breed cross embryos were somewhat larger than two-breed cross embryos. However, the increased pig survival from birth to weaning was not due to heavier pig birth weights as there was essentially no difference in birth weights for pigs from purebred and crossbred gilts.

Table 5. Litter Size and Pig Survival for Crossbred Litters from Purebred Gilts and Three-Breed Cross Litters from Crossbred Gilts

Breed Group[a]	No. Litters[b]	No. embryos 30 days postbreeding	Embryo survival rate, %	Litter size at birth	Litter size at weaning	Pig survival to weaning, %
		Gilts mated to Duroc sires				
DxH	23-31	9.2	73.5	8.4	7.0	82.4
DxHY	63-66	11.0	84.7	10.5	8.7	82.1
DxY	23-29	10.1	77.8	9.0	7.2	83.8
		Gilts mated to Hampshire sires				
HxD	25-34	10.4	77.3	9.3	6.5	68.8
HxDY	68-64	11.6	83.5	10.2	7.9	77.7
HxY	17-30	11.6	80.7	10.7	7.3	68.5
		Gilts mated to Yorkshire sires				
YxD	28-35	12.2	85.7	9.2	7.3	78.3
YxDH	61-69	10.7	82.1	10.0	8.3	83.8
YxH	29-34	9.1	66.5	9.3	7.0	76.2
3-breed crosses		11.1	83.4	10.2	8.3	81.2
2-breed crosses		10.4	76.9	9.3	7.1	76.3
Crossbred gilt advantage		+.7*	+6.5*	+.9*	+1.2*	+4.9*

[a]First letter represents breed of sire and second breed or breeding of gilt (D=Duroc, H=Hampshire, Y=Yorkshire, DH=Duroc-Hampshire cross, etc.).

[b]First column is the number of gilts slaughtered and the second is number of gilts farrowed.

*Significant advantage for crossbred females.

It is readily apparent that commercial producers through crossbreeding should be able to attain higher pig survival rates and consequently larger litter size at weaning than purebred producers. It is important, however, that the crossbreeding program be designed to make maximum use of the advantages of crossbreeding. Table 6 shows the percentage of the total advantage of crossbreeding that is realized by various crossbreeding systems. To get 100% of the advantage we must have a crossbred female and 100% crossbred pig. From tables 2 and 3 we see that this total advantage results in an increase in 1.9 pigs weaned per litter over purebred systems (.7 pigs per litter for purebred sows with crossbred pigs and 1.2 pigs per litter for crossbred sows with crossbred pigs). If we realize just 67% of the advantage this means specifically that we can expect the increase in litter size of the crossbreeding system compared to purebreds to be .67 x 1.9 or 1.23 pigs. Consequently, the litter size weaned is expected to be .63 pigs per litter less than if we have 100% heterosis.

Table 6. Percent Heterosis in Various Crossbreeding Systems

Sequence of boar breeds	% Heterosis Pig	% Heterosis Dam	Expected reduction in litter size weaned due to heterosis loss
Purebred boar systems			
1. A♂ x(BC♀)→ sell all pigs	100	100	0
2. A-B-A-B, repeat	67	67	.63
3. A-B-C-A-B-C, repeat	86	86	.27
4. A-B-C-D-A-B-C-D, repeat	93	93	.13
Crossbred boar systems			
5. AxB-AxB-AxB, repeat	50	50	.95
6. AxB-AxC-AxD, repeat	71	71	.55
7. AxB-BxC-CxA, repeat	71	71	.55
8. AxC-BxD-, repeat	83	83	.32
9. AxB♂ (Rotation female:C-D-E)*	100	86	.17
10. (AxB)♂x(CxD)♀→ sell all pigs	100	100	0

*System where part of herd is set aside to produce replacement females and sire breeds C, D and E are rotated for production of females. Market pigs are produced by mating these females to terminal cross sires.

Crossbreeding systems with crossbred boars are shown because of the recent interest in their use. Limited research shows that crossbred boars are sexually more aggressive than purebreds and that conception rates may be higher for females mated to crossbred boars. In view of this, they may have a place in commercial production. Whether purebred or crossbred boars are used, they must be mated in a way that maintains high levels of heterosis. All of the advantage of crossbreeding can be realized only with terminal crosses (1 and 10). Both purebred and crossbred boars can be used in ways that give high levels of heterosis that should yield maximum baby pig survival. At the same time, both can be used in ways that give lower levels of heterosis that will result in some reduction in baby pig survival.

The advantages of crossbreeding are real and do increase baby pig survival. Different producers may desire different systems, but maximum utilization of breed differences and heterosis will be realized by using crossbred sows of breeds that are superior in litter size and mothering ability and mating them in a way that retains maximum heterosis.

Physiological Factors Affecting Breeding and Reproductive Efficiency of Boars

R. P. WETTEMANN

A MAJOR GOAL FOR ALL SWINE PRODUCERS IS TO MAXIMIZE REPRODUCTIVE PERFORMANCE. Although boars greatly influence conception rate, they are often neglected. Optimum management of boars has the potential to increase profit by increasing the number of pigs born per sow per year.

SOCIAL FACTORS INFLUENCE PERFORMANCE OF BOARS

The interaction of growing boars with other young boars and gilts can influence their breeding performance after puberty. If boars are socially restricted during growth, they have less interest in gilts and are not as vigorous as boars raised with either other boars or gilts. The effect appears to be present in later life and the sexual performance of boars raised in isolation doesn't improve with sexual experience or age.

Housing of mature boars near sows may also influence their sexual performance. The association of boars with females usually increases their libido or sex drive. Therefore, boars that have been sexually rested or removed from sows for a period of time may not be as sexually aggressive as they were during the last breeding season. Several weeks of sexual experience may be necessary for them to return to their maximum breeding performance.

CAN HORMONE TREATMENTS BE USED TO INCREASE LIBIDO?

All boars are not sexually aggressive. After the normal age of puberty, (about 6 months) some boars still lack the desire or ability to mate. The lack of libido could be caused by abnormal testicular development, undesirable social interactions, stress or other factors. Although injections of testosterone, the major male sex hormone, may result in increased libido in some boars, it should not be given. Besides the desire and ability to ejaculate, boars must also produce sufficient numbers of fertile sperm. Treatment of boars with testosterone causes a reduction in the secretion of gonadotropic hormones from the animals anterior pituitary gland. Gonadotropic hormones are necessary for normal sperm production. Thus treatment with testosterone could reduce or eliminate sperm production. Testosterone treatment may increase the sexual aggressiveness of some boars, but the boars will probably be infertile due to a reduction in the number of normal sperm.

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SEMEN EVALUATION AND TEST-MATING

Reproductive efficiency can be greatly improved by eliminating boars that are sterile or may have reduced fertility, before the start of the breeding season. Semen evaluation and test-mating is especially important when young boars are introduced into a herd.

Sexual aggressiveness can be evaluated by taking an estrus gilt to the boar and observing his desire to mate. Assist the boar if necessary and allow him to mate. Observe the gilt 17-22 days after mating to determine if she becomes pregnant or returns to estrus. A semen sample can be collected from most boars by the gloved-hand technique while they are mounting an estrous gilt. Evaluation of the semen for volume, sperm concentration and sperm motility by a qualified person will help to eliminate those boars which will probably have low fertility. However, no boar should be culled based on one semen evaluation. Several evaluations at approximately two week intervals should be performed before deciding whether the semen quality problem is temporary or permanent.

BREED EFFECTS ON REPRODUCTIVE EFFICIENCY

Few reports are available which characterize breed differences for male reproductive efficiency. Some of the advantages of crossbred gilts for increased reproductive performance may also exist for crossbred boars. A study was conducted to evaluate testicular development and mating performance of purebred and crossbred Duroc and Hampshire boars.

Table 1. Reproductive performance of Purebred and crossbred boars.[a]

Breed group[b]	Testes		Percent gilts preg.	No. embryos per pregnant gilt
	weight (g)	no. of sperm (X109)		
D X D	564.5	54.4	63.2	11.0
D X H	652.3	67.9	67.5	11.5
H X D	717.7	76.4	60.0	11.0
H X H	614.9	60.6	48.6	10.3

[a] Wilson et al. J. Anim. Sci. 44,:939 (1977).

[b] D = Duroc, H = Hampshire, breed of sire listed first.

At 7.5 months of age, testes weight and total sperm content were greater for Hampshire boars than for Duroc boars, but both purebreds had lighter testes with less total sperm than crossbred boars.

When the boars were mated to Yorkshire gilts the percent pregnant was reduced for Hampshires boars compared to Durocs or crossbred boars. However, the number of embryos at 30-days after breeding was similar for pregnant gilts mated to purebred and crossbred boars. Twenty-eight of 36 crossbred boars mated each time they were exposed to an estrus gilt but only 11 of 36 of the purebred boars mated each time. None of the crossbred boars failed to mate more than once, while 15 of

36 purebred boars failed to mate two or more times.

Although little information is available on the reproductive performance of different breeds and crossbred boars, there appears to be breed differences. Evaluation and selection of breeds of boars based on sperm production and mating behavior may be a possible way to increase reproductive efficiency.

INFLUENCE OF HEAT STRESS ON REPRODUCTIVE PERFORMANCE

Decreased conception rates and reduced litter size are observed when sows are mated during the summer months. In most operations it is not possible to avoid breeding during the hot months. Therefore, it is necessary to determine the effects of heat stress on reproduction and to find the best management systems to increase reproductive performance when swine are exposed to elevated ambient temperature.

Local heating of the scrotum of boars for three hours causes a reduction in the number of live sperm ejaculated. When boars are exposed to elevated ambient temperatures for several days decreased numbers of sperm are ejaculated and the sperm are less fertile. Some of our recent studies have investigated the influence of elevated ambient temperature on reproductive performance of boars.

RECOVERY OF NORMAL SEMEN QUALITY AFTER HEAT STRESS

Six Yorkshire boars of proven fertility were allotted to each of two temperature controlled chambers. After a two-week adjustment period at 74° F, control boars were maintained at 74° F and treated boars were exposed to 88° F from 5 pm to 9 am and 94° F from 9 am to 5 pm. After 75 days of heat stress all boars were exposed to 74° F daily for six weeks. Boars were ejaculated twice weekly and semen quality was evaluated weekly.

The quality of the sperm cells was reduced by heat stress. In figure 1, motility of sperm from heat stressed boars is compared to that for control boars. During the three weeks prior to heat stress, sperm motility was similar in both groups of boars (averaged 80%). After two weeks of treatment, sperm motility decreased to 56% in stressed boars. And during three to six weeks of treatment, only half as many motile sperm were obtained from heat stressed boars as from control boars.

After the five week breeding period, heat stressed boars had 53% motile sperm whereas control boars had 85% (figure 1). Sperm motility increased when stressed boars were exposed to a cool temperature (74° F). But it was not until five weeks after the end of heat stress, that sperm motility was similar for stressed and control boars. Therefore, if sperm are affected in the formation stages by increased body temperature due to heat stress, the influence is present for up to five weeks later.

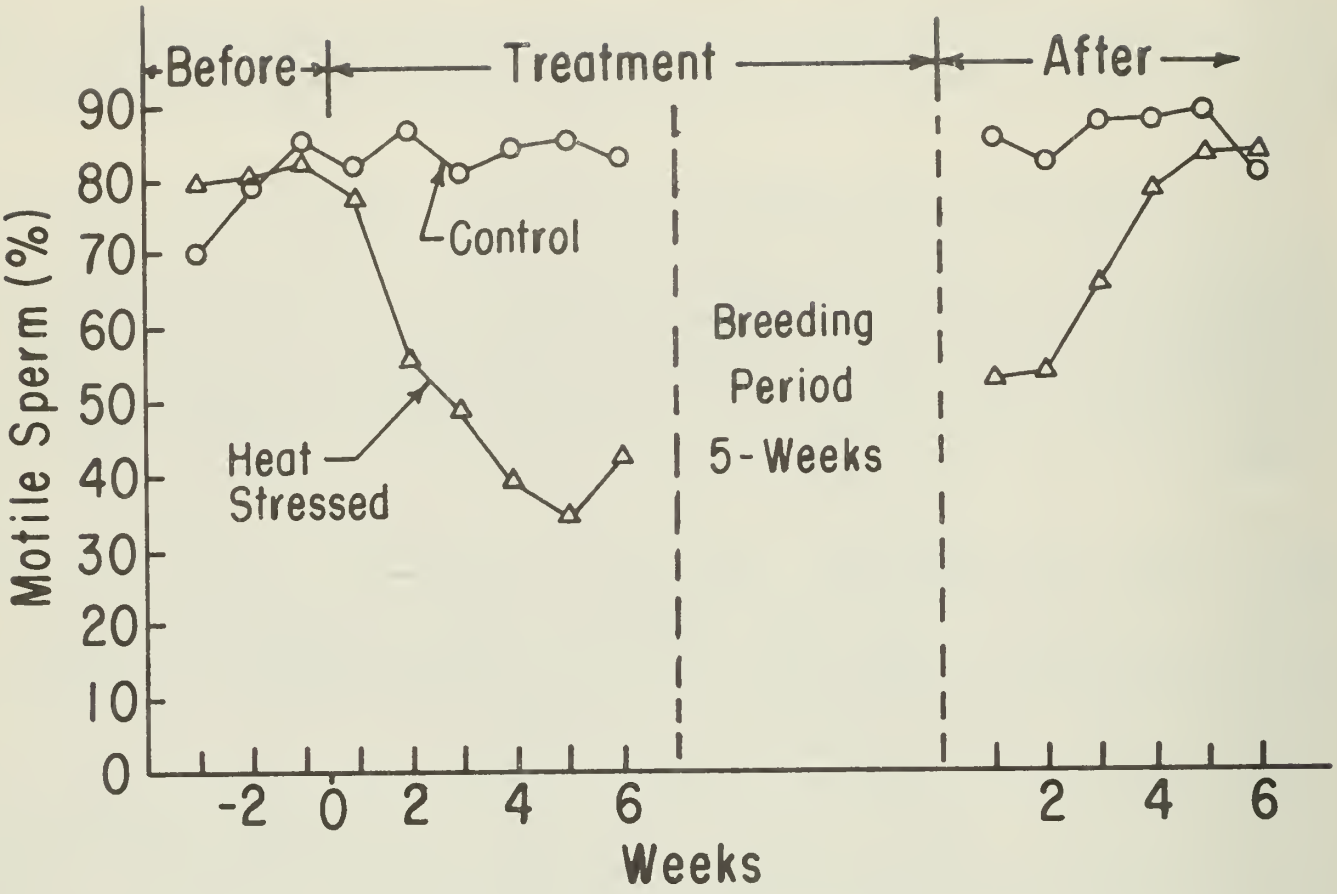

Figure 1. Motility of sperm from boars before, during and after heat stress.

Fertility was reduced when gilts were naturally mated to boars after six weeks of stress (table 2). Eighty-two percent of the gilts bred to control boars conceived, but only 59% of the gilts bred to heat stressed boars were pregnant. Embryonic survival at 30 days after breeding was similar for gilts bred to control or heat stressed boars. Gilts that were bred to control boars had an average of 10.9 embryos and gilts bred to heat stressed boars had 10.7 embryos.

Table 2. Fertility of Gilts Bred to Control or Heat Stressed Boars.

Treatment	No. Boars	No. Gilts Bred	Gilts Pregnant		
			No.	Percent	Embryo Survival (%)
Control	6	37	30	82	82
Heat Stressed	6	40	25	59	82

COMPARISON OF BOAR COOLING METHODS ON REPRODUCTIVE PERFORMANCE

Eighteen boars were used in this experiment during May through October. Six boars were housed in a temperature controlled chamber at approximately 70° F. A second group of six boars was kept in outside lots with a shade provided and a third group of six boars was kept in outside lots provided with a shade and a water sprinkler from June 1 until September 15. During a three week breeding period which started on August 11, each boar was hand mated to 5 or 6 gilts.

The temperature in the cool chamber ranged from 55 to 75° F during the trial. Ambient temperature, in El Reno, Oklahoma increased from an average weekly maximum of about 83° F during the last two weeks of May to 104° F during the second week of August.

The respiratory rates (RR) of the boars were directly related to the ambient temperature. When boars are exposed to elevated ambient temperatures, increased evaporative cooling by the respiratory passages is a major way excess heat is removed from the body. During the last two weeks in May and the first week in June, RR were similar in all boars. But as ambient temperature increased RR increased rapidly in boars with only shade, reaching a maximum of 144 breathes per minute in August. During August, when boars were supplied with sprinklers as well as shade, RR were only slightly greater than those for boars in the cool chamber. These results indicate that boars given only shade were heat stressed, but if sprinklers were supplied the effect of high ambient temperature was greatly reduced. The effectiveness of sprinklers for cooling boars would depend on the relative humidity, which would influence the rate of evaporative cooling.

Similar to previous studies, semen volume was not influenced by heat stress. Although boars were not trained for semen collection on a dummy, it was possible to obtain ejacula from 17 of the 18 boars at each of the collection times. In June, before boars were exposed to high ambient temperatures, semen quality was similar for boars on all treatments. At the August evaluation period, the percent motile sperm was reduced for shade boars compared to cool chamber boars or boars with shade and sprinklers. Shade boars also had a greater percentage of abnormal sperm in their ejacula than the other boars.

The influence of the different cooling systems on boar fertility is shown in table 3. All gilts were provided with shade and sprinklers during the study. Thus any differences in fertility are due to the effects of heat stress on the boars. When boars received only shade, 44.1 percent of the gilts were pregnant 30 days after breeding. If boars were sprinkled in addition to shade, 63.9 percent of the gilts became pregnant. Maintaining boars in a cool chamber during the hot summer resulted in no significant improvement in fertility compared to boars with both shade and sprinklers. Litter size for the pregnant gilts at 30 days after breeding was not significantly influenced by treatment.

Table 3. Fertility of Gilts Bred During August 1977 to Boars Maintained with Shade, Shade and Sprinklers or in a Cool Chamber During the Summer.

Treatment	No. of Boars	No. of Gilts Bred	Gilts Pregnant at 30 Days		
			No.	Percent	No. of Embryos
Shade	6	34	15	44.1	11.8±.6
Shade and Sprinkler	6	36	23	63.9	10.6±.5
Cool Chamber	6	31	21	67.8	10.4±.7

The fertility of the boars provided with both shade and sprinklers and the cool chamber boars was about 10 to 15 percent less than we normally observe when breeding during cooler months of the year. This reduction in fertility could be related to heat stress of the gilts or to sexual rest of the boars. The boars were not used for breeding nor was semen collected during the six weeks preceding the breeding season. Semen quality in most males is reduced after a period of sexual rest.

All boars are not affected the same by heat stress. Heat stress may completely inhibit sperm production in some boars but only cause slight reductions in semen quality in others. In table 4, boars are ranked into fertility groups. Five of six boars receiving only shade settled 50 percent or less of the gilts bred. Whereas, only two of the boars with shade and sprinklers and one boar maintained in a cool chamber settled 50 percent or less of the gilts that they were mated with. None of the shade treatment boars settled as many as 75 percent of the gilts with which they were mated. However, two of the boars with shade and sprinklers and three of the boars in a cool chamber settled more than 75 percent of the gilts that they were mated with.

Table 4. Fertility Rank of Individual Boars Maintained with Shade, Shade and Sprinklers or in a Cool Chamber During the Summer of 1977.

Treatment	Number of Boars That Settled the Following Percentage of the Gilts Bred		
	<50%	51-74%	>75%
Shade	5	1	0
Shade and Sprinklers	2	2	2
Cool Chamber	1	2	3

Based on these trials, it appears that under Oklahoma conditions, evaporative cooling from the body surface of boars is sufficient to maintain acceptable fertility during summer months and air conditioning is not necessary. When air

temperature gets above 80° F, if boars are provided with sprinklers along with shade, this should be sufficient to prevent heat stress.

SUMMARY

Reproductive efficiency can be increased by proper management of boars. Boars cannot be neglected until the start of the breeding period if maximum fertility is desired. The formation of sperm is a continual process which requires about 6 weeks from the initiation to ejaculation. If sperm are affected in the formation stages, the influence may be apparent much later. Good management practices coupled with test-mating of gilts and semen evaluation will result in more pigs born per sow per year.

Physiological Factors Affecting Breeding and Reproductive Efficiency of Female Swine

FULLER W. BAZER

THE NUMBER OF PIGLETS PRODUCED BY GILTS AND SOWS IS INFLUENCED BY FOUR MAJOR FACTORS. First, the number of ova ovulated sets the upper limit on litter size, since each ovum represents one potential piglet if the possibility of maternal twins is excluded. Second, the ova must be fertilized and failure of some to be fertilized reduces the number potential offspring. Third, embryonic mortality claims a significant percentage of the fertilized ova, primarily during the early stages (Days 6-30) of pregnancy. The fourth factor may be called uterine capacity and implies more than the physical surface area of the uterus, that is, it also refers to the variability in uterine physiology between females which may affect litter size. It is difficult to separate out the factors which may influence embryonic mortality and uterine capacity due to interactions between the uterus and conceptus which lead to successful embryonic development. The term conceptus is used to refer to the embryo and its associated membranes and fluids.

In the following sections, an attempt will be made to discuss factors which ultimately control litter size in gilts and sows.

OVULATION RATE

The average number of ova ovulated by gilts is affected by breed, degree of inbreeding, level of nutrition, age, parity and other variables. Generally, however, gilts ovulate 12-15 ova and sows produce perhaps 14 to 20 ova. It is immediately obvious that average litter size is almost never equal to these figures. But, the question of whether or not increasing ovulation rate would lead to increased litter size is legitimate and studies have been done in an attempt to answer that question.

The number of potential embryos (ova ovulated) can be increased by hormonal superovulation with Pregnant Mare's Serum Gonadotropin (PMSG), transfer of extra embryos to an already pregnant uterus or through nutritional superovulation or "flushing". None of these techniques has led to a statistically significant improvement in average litter size, but increases of up to 2.0 piglets born per litter have been reported (Table 1).

The results summarized in Table 1 can be used to demonstrate two points. First, the estimates of litter size at 25-40 days of gestation and near term are much more comparable in control females than in those which have been superovulated. This is consistent with results from numerous researchers who have concluded that the major period of embryonic death is before Day 30 of gestation in swine (Wrathall, 1971). The second point is that superovulated gilts and sows have two periods of embryonic/fetal loss. There is a considerable loss of embryos by 25 to 40 days as also seen in control females; however, there is also a period of fetal death subsequent to Day 40. The precise time of this second period of fetal death in superovulated gilts has not been determined, but other data (Knight et al., 1977; Geisert, 1978)

suggest that much of the fetal death occurs between Days 40 and 70 of pregnancy. In any event, most of the apparent advantage in average litter size (2.5 to 6.8 embryos) is lost by the the time of farrowing.

Table 1. Attempts To Increase Litter Size By Superovulation with Pregnant Mares Serum Gonadotropin

Reference	Parity	Treatment[a]	Corpora Lutea	Litter Size[b]	
				Days 25-40	>90 days
Pope et al. (1968)	Gilts	C	11.6	10.6(3)	8.3(3)
		S	19.7	14.0(3)	10.3(3)
Longenecker and Day (1968)	Sows	C	13.1	10.1(18)	9.3(12)
		S	25.1	15.3(19)	11.3(20)
Bazer et al. (1969)	Sows	C	15.6	12.2(6)	12.1(12)
		S	22.9	17.4(6)	10.0(12)
Dziuk (1968)	Gilts	C	13.4	9.9(30)	—
		S	35.0	12.4(18)	—
Hunter (1966)	Gilts	S	37.0	18.8(6)	—
Longenecker et al. (1965)	Sows	C	11.5	9.0(6)	—
		S	23.9	15.8(9)	—

[a]C = Control; S = Superovulated
[b]Number of animals indicated in parentheses

Wrathall (1971) has summarized a large volume of data which indicate that there is a marked increase in percent embryonic mortality in swine as ovulation rate increases. One may argue that the hormonally superovulated gilt is likely to have endocrine imbalances which favor embryonic death. However, recent data (Geisert, 1978) indicate that gilts selected for a high ovulation rate (19 to 20 ovulations) have a higher embryonic death loss than control gilts (14 to 15 ovulations). Litter size in the select line was 13.7 and 11.1 at Days 30 and 70 of gestation, respectively, while control gilts had an average of 11.1 and 10.1 embryos at the same respective periods. These data add further support to the notion that increasing ovulation rate will not, in itself, lead to a marked increase in litter size.

It is important to note, however, that the variability in litter size increases following hormonal superovulation. For example, Longenecker and Day (1968) reported that 10% of their superovulated sows had more than 15 piglets farrowed. Perhaps more attention should be focused on gilts and sows which have demonstrated their ability to maintain a large litter to term. Studies of endocrine and uterine

function and conceptus development in these "superior" individuals may be more likely to increase our understanding of factors associated with prolificacy than studying a random population of gilts.

Ovulation rate can be increased by selection, hormonal superovulation and nutritional superovulation and is not, therefore, a factor likely to deter progress in increasing prolificacy in swine.

FERTILIZATION RATE

Wrathall (1971) has summarized abundant evidence which indicates that 90 to 100% of the ova ovulated are fertilized when good swine breeding practices are followed and boars of proven fertility are used. Furthermore, hormonal superovulation has not been found to have an adverse affect on fertilization rate. Therefore, fertilization failure does not appear likely to impede progress toward increasing litter size in swine.

EMBRYONIC MORTALITY

Factors associated with embryonic mortality are, at best, vaguely understood. Therefore, a systematic consideration of critical periods in conceptus development may help to point out when embryonic/fetal death losses occur and to speculate on possible causes of developmental failure.

BLASTOCYST DEVELOPMENT

Corner (1923) and Perry and Rowlands (1962) found a major portion of embryonic loss to occur between Days 6 and 9 of pregnancy in gilts and sows. This period coincides with the time that the blastocyst must shed a thick mucopolysaccharide membrane (zona pellucida) and begin to expand from a diameter of about .6 mm on Day 7 to about 2 mm by Day 9. Perry and Rowlands (1962) found that about two-thirds of the embryonic loss occurred by Day 9 and most of the remaining 33% occurred by Day 18 of pregnancy.

No general explanation can be offered for failure of the early blastocysts to continue to develop. Genetic abnormalities, however, may account for as much as 10% of the loss (McFeely, 1967).

The pig embryo increases from a diameter of about 2 mm on Day 9 to 4 to 6 mm on Day 12 and is spherical in shape. Between Days 12 and 16 the blastocyst elongates to about 1000 mm in length and some 2 mm in diameter. These blastocysts each occupy only about a 200 mm linear portion of the uterus due to extensive folding of the uterine wall. The mechanisms controlling this process of elongation are not understood. Perry and Rowlands (1962) reported that failure of blastocysts to elongate and the presence of "abnormally" short blastocysts may account for a significant portion of embryonic mortality.

In addition to the physical process of elongation, the pig blastocysts begins to

produce estrogens by Day 12 of pregnancy (Perry et al. 1976). Initially this estrogen is believed to act on the uterus to prevent the release of prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$) into the uterine veins (Bazer and Thatcher, 1977). By preventing $PGF_{2\alpha}$ release, the corpora lutea (CL) which produce progesterone are protected and remain functional for the duration of pregnancy. In nonpregnant animals, on the other hand, $PGF_{2\alpha}$ is released into the uterine vasculature between Days 12 and 16 causing the CL to regress and the gilt will then return to estrus. In the pregnant animal, therefore, each embryo provides a signal to the uterine endometrium, with which it is associated, to prevent $PGF_{2\alpha}$ release. If that signal is not given by an adequate number of blastocysts or if it is given too late the pregnancy would likely fail completely.

This notion may, however, apply equally well to individual blastocysts within the litter which, if delayed in development, do not create proper stimulation of the endometrium with which they have contact. The consequence of this would be failure to those embryos to develop normally or death of those blastocysts.

In addition to the blastocysts role in protecting the CL, the estrogens produced act to: (1) increase the rate of blood flow to the uterus; (2) increase capillary permeability to nutrients and gases and (3) promote water and electrolyte movement to the site of placentation.

DEVELOPMENTAL OF PLACENTAL MEMBRANES

As mentioned previously, the pig embryo elongates very rapidly between Days 12 (4-6 mm) and 15 (~ 1000 mm) of pregnancy. This affords the blastocyst a large surface area for absorption of nutrients which are secreted into the uterine lumen by the epithelial cells of the uterine endometrial glands. The membrane which undergoes this rapid elongation is called the trophoblast and will form one of the placental membranes. The other component of the blastocyst is called the embryonic disc and it will give rise to the embryo.

An analogy will now be drawn between the continued development of the embryo and the inflation of a football. The trophoblast or chorion may be considered the outer "pigskin" of the football and up to day 17 or 18 of pregnancy it is in the noninflated state. Then a membrane grows out of the hind-gut of the embryo and into the chorionic sac. The allantois may be equated to the bladder of the football. The allantois accumulates water very rapidly causing the chorionic and allantoic membranes to be pushed into contact with each other and then both membranes are forced into intimate contact with the endometrial surface of the uterus.

Evidence from studies by Goldstein (1977) indicate that the transport of water into the allantoic sac is an active transport process controlled, in part, by estrogen and progesterone in the appropriate ratio and possibly by other steroid and protein hormones of placental origin. An understanding of how we may manipulate allantoic fluid volume and its subsequent effect on placental development and, in turn, fetal development and survival appears worthy of continued study.

Failure of adequate water to be transported into the allantois may result in reduced

placental surface area. This would reduce the effective area for placental transport of nutrients to the fetus in adequate amount for normal fetal development. Data from our laboratory indicate that "uterine crowding" leads to a significant ($P < .01$), reduction in allantoic fluid volume and placental weight, length and surface area (Knight et al., 1977). This is then associated with a decrease in rate of fetal growth and an increase in fetal deaths. A major portion of the fetal deaths occurred between Days 40 and 70 of gestation.

In gilts and sows with a "normal" ovulation rate there appears to be little embryonic mortality after Day 30 of gestation. However, if the number of potential embryos per uterine horn is increased by hormonal superovulation, the addition of extra embryos by embryo transfer or restriction of essentially one whole litter of embryos to one uterine horn, a period of fetal death also occurs. Consequently, apparent advantages in litter size observed at 25 to 40 days of gestation are either absent or markedly reduced at farrowing.

ROLE OF UTERINE SECRETIONS

The glands of the pig uterine endometrium produce a complex secretion which, is known as uterine milk. This material is presumed to serve as a complex medium for nutrition of the embryo before and after placentation. Before placentation the trophoblast appears to absorb this secretion. Then, after placentation, specialize structures, called areolae, develop where the chorioallantois comes to lie in contact with openings of the uterine glands. There are 2000 to 3000 areolae for each placenta. The number of areolae and consequently areolae surface area is reduced for each conceptus as litter size increases. This may also be of importance in explaining the higher rate of fetal deaths and slower rate of fetal growth as conceptus density in the uterus increases.

Uterine milk is composed of carbohydrates, lipids, minerals, vitamins, water, amino acids and proteins and can, therefore, provide most or all essential nutrients to the conceptus. Our research has concentrated on the proteins present in uterine milk. An understanding of the hormonal regulation of secretion of these proteins and their role has been of primary interest. Proteins have been identified which serve as enzymes. These include leucine aminopeptidase, lysozyme, cathepsins, esterases and phosphatases. Other proteins appear to serve as carrier molecules to transport substances from the uterine endometrium to the conceptus. Proteins have now been identified which transport iron and two forms of vitamin A (retinol and retinoic acid). Two size classes of protein bind progesterone, but this binding is nonspecific and the significance of this binding is not known.

The iron transport molecule has been studied most extensively and will be discussed in more detail. This protein is a progesterone induced glycoprotein (initials spell PIG) which binds one atom of iron. PIG is secreted by the epithelial cells of the uterine glands when they are exposed to a high progesterone low estrogen environment. Therefore, peak secretion of PIG occurs between Days 12 and 20 and Days 35 to 75 of pregnancy when progesterone levels are high relative to those of estrogen.

PIG is secreted into the lumen of the uterine glands and, after areolae formation,

it is transported via the areolae into the allantoic sac. Within the allantoic fluid the purple protein gives up its iron in the ferrous (Fe^{2+}) state. This is the proper valence state for absorption by gut epithelium. As pointed out earlier, the allantois is derived from the hind-gut of the embryo. The iron then becomes available to the fetus for storage, synthesis of hemoglobin and other functions for which iron is required.

If PIG is the primary mechanism for transporting iron from the dam to her fetuses, the fact that this is occurring primarily between Days 35 and 75 of pregnancy suggests that administration of iron to the sow after Day 90 of gestation would have little effect on iron stores of the newborn piglet.

Ducsay (1977) injected sows with iron (7.3 mg/kg body weight) on Days 40, 50 and 60 of gestation and found their piglets to have higher hemoglobin levels at 8 $\pm$ 1 hr after birth (Experiment I) and on Day 7 post-farrowing (Experiment II). Sows administered iron on Days 90, 100 and 110 produced piglets with hemoglobin levels comparable to those of piglets born to untreated control sows.

In a subsequent study, gilts injected with iron (7.3 mg/kg body weight) on Days 40, 50 and 60 of pregnancy were hysterectomized on Day 90. Their conceptuses were evaluated for iron stores. Fetal liver total iron and allantoic fluid iron concentration were greater in conceptuses from treated as compared to untreated gilts. Although further studies are needed and are in progress, these data indicate that fetal iron stores may be improved by supplementing iron intake of the sow when placental transport of PIG is maximal, i.e., Days 30 to 75 and not during the last month of gestation as is currently practiced.

The preceding discussion of the synthesis, secretion and transport of iron by PIG may also be applicable to the synthesis, secretion and transport of other minerals, vitamins and possibly some hormones from dam to fetus. The synthesis and secretion and transport of these nutrients in adequate amount is presumed to be essential for normal fetal growth and survival.

FETAL GROWTH AND SURVIVAL

Available data indicate that embryonic/fetal mortality increases and average birth weights of piglets decrease as litter size increases. As summarized in Table 2, Knight et al. (1977) found that average daily gain of fetuses, especially after Day 70, was reduced due to intrauterine crowding. They removed one ovary and one uterine horn from gilts which, due to compensation in ovulation rate by the remaining ovary, resulted in essentially one litter of embryos confined to about one-half the uterine endometrial surface area for control gilts. Fetal weight averaged 878.5 gm for control fetuses and 709.5 gm for fetuses from treated gilts at Day 100 of pregnancy. In addition, fetal survival was significantly reduced in the treated gilts.

Table 2. Effect of Intrauterine Crowding on Rate of Fetal Growth

Stage of Gestation	Control		UHOX[a]	
	Weight Gain, gm	Av. Daily Gain, gm	Weight Gain, gm	Av. Daily Gain, gm
20-25	.47	.09	.31	.06
25-30	1.06	.21	.95	.19
30-35	2.20	.44	2.40	.48
35-40	5.70	1.14	5.40	1.08
40-50	32.00	3.20	23.20	2.32
50-60	76.00	7.60	61.80	6.18
60-70	95.30	9.53	105.40	10.54
70-80	246.20	24.62	149.70	14.97
80-90	213.50	21.35	117.70	11.77
90-100	301.40	30.14	242.60	24.26

[a]UHOX - unilaterally ovariectomized-hysterectomized gilts having essentially one litter of embryos confined to about one-half the uterine surface are of the controls.

In terms of factors associated with reduced fetal growth rate and survival, placental insufficiency was the most obvious possibility. However, reduced uterine endometrium surface area, altered hormonal balance and reduced avialability of uterine secretion are other factors which may help to explain the observations of Knight et al. (1977). We believe these factors are related to the general problem of embryonic/fetal motility in swine. Therefore, our research efforts continue to be directed at developing an understanding of the physiology and endocrinology of the uterus and conceptus, as well as that of the sow, which may regulate blastocyst development, placentation and uterine secretory activity.

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University of Illinois

PORK INDUSTRY CONFERENCE

December 6-7, 1979
College of Agriculture
Department of Animal Science
Cooperative Extension Service
Agricultural Experiment Station
University of Illinois at Urbana-Champaign

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Issued in furtherance of Cooperative Extension Work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. JOHN B. CLAAR, Director, Cooperative Extension Service, University of Illinois at Urbana-Champaign. The Illinois Cooperative Extension Service provides equal opportunities in programs and employment.

WELCOME TO THE PORK INDUSTRY CONFERENCE! It is a pleasure to have you attend.

Commercial swine production has become industrialized. It is now a business in which experts in animal production, more than ever, must be concerned about finance, personnel management, labor efficiency, quality control, industry image, government regulation, etc. In other words, it is big business which requires constant awareness of advancements in technology, changes in organizational management and government policies and changes in the factors of production. Only those who make an effort to be informed in all facets of the business will be likely to operate profitably.

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You are here because you need and value information to apply to your business. We hope to provide it.

We will be interested in your suggestions to make future conferences of maximum benefit to you.

D.E. Becker, Head
Department of Animal Science

The Department of Animal Science at the University of Illinois

THE DEPARTMENT OF ANIMAL SCIENCE IS CONCERNED WITH THE MULTIDISCIPLINARY ACTIVITIES associated with the production, care, and utilization of animals useful to mankind. It includes primary fields of study in genetics, environmental physiology and management, meat science and muscle biology, nutrition, reproductive physiology, and some emphasis on aquatic biology and behavior. Beef cattle, horses, poultry, sheep, swine, and various companion and laboratory animals are studied to assist animal producers and owners to obtain more efficient performance, more economical production and other such improvements which ultimately benefit the general public.

Our staff includes about 140 people, of whom 50 are academic staff menbers; 40 are nonacademic staff members in the offices, research farms, and laboratories; and about 50 are part-time teaching or research assistants who are pursuing graduate study. Several of the senior academic staff members have received national and international recognition for their accomplishments.

The work of the Department is divided into extension, research, and teaching. Extension or off-campus teaching is handled by eight full-time staff members. Each extension specialist conducts seminars, clinics, field days, etc., for livestock or poultry producers. Their primary work is to apply new research findings to the business of animal production or product processing.

Over the years the Department has had very active and productive research programs. Some of the more notable research accomplishments include the discovery of the value of antibiotics in livestock feeding, the elucidation of the amino acid needs of swine and poultry, the utilization of inorganic nitrogen by ruminants, the development of simplified corn-soybean meal rations for swine feeding, and the development of confinement production technics, particularly the use of slatted floors. Current research studies pertain to such topics as recycling of animal wastes, decreasing prenatal mortality in gestating sows, the inheritance of blood groups in swine, and maximizing the utilization of corn stalks by brood cows.

With the recent increase in student numbers, the teaching load in Animal Science increased significantly. At present our Department provides instruction for about 2,600 students a year in the classroom, and staff members advise 350 undergraduate (mostly juniors and seniors) and 85 graduate majors. Our graduates have many opportunities for employment.

The future of the Department of Animal Science appears bright. Meat consumption and the use of animals for companionship and in recreational activities are at all-time highs and seem likely to increase further. Such an expanding animal industry will require an educational program to produce well-trained animal scientists and research programs geared to produce new and improved technology.

University of Illinois
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December 6 and 7, 1979
Ramada Inn, Champaign

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Protein-Amino Acid Requirements of Swine

D.H. BAKER AND R.A. EASTER

Optimum performance requires that any indispensable amino acid be fed at the proper level and time, and with the proper level of energy and all other indispensable nutrients.[1/] Swine will perform satisfactorily if these conditions are met, even though there may be some variation in the level of crude protein in the diet. Because gilts and boars are generally leaner than barrows, they require higher levels of crude protein to meet amino acid requirements. Also, maximal carcass leanness requires a greater intake of amino acids than maximal rate of weight gain. Maximization of feed efficiency also generally requires higher levels of amino acids than those required for maximization of weight gain.

AMINO ACID REQUIREMENTS OF SWINE

Requirements for indispensable amino acids by swine of various weights and in different stages of production are shown in Table 1. In all cases the requirements refer to the amount of natural L-isomer required. When amino acid supplements are provided, DL-methionine can replace the L-isomer in meeting the need for methionine (or cystine). D-tryptophan has a biological activity of about 60 percent relative to L-tryptophan for growing swine. Hence DL-tryptophan has 80 percent activity. D-lysine, on the other hand, has no activity whatever, and therefore the mixed DL-isomer has 50 percent activity relative to L-lysine. Commercial lysine is provided as L-lysine·HCL (98 percent pure) such that the lysine activity is 78.4 percent (80 percent lysine in L-lysine·HCL x 98 percent purity).

Pigs can synthesize arginine at a rate sufficient to meet 60 to 75 percent of the requirement for normal growth, but a small amount must be provided from a dietary source to fulfill the total need of growing-finishing swine. For gravid and nongravid postpubertal female swine, synthesis by the animal completely satisfies the arginine need. Cystine can satisfy at least 50 percent of the total need for sulfur-containing amino acids (methionine + cystine) and tyrosine can likewise supply at least 50 percent of the total need for aromatic amino acids (phenylaline + tyrosine). Methionine in excess of its requirement for protein synthesis can spare dietary choline (4.3 mg methionine is equal in methylating capacity to 1 mg choline).

The amino acid requirements of growing-finishing swine expressed in terms of dietary concentration increase as the level of dietary protein and caloric density of the diet increase. Because the amino acid concentration of lean tissue remains essentially constant with age, and because maintenance needs constitute a small percentage of total needs, it is assumed that the requirements for indispensable amino acids remain a constant percent of the protein with advancing age and weight.

[1/] Other than the 10 indispensable amino acids, the nutrients that must be added at supplemental levels to corn-soybean meal diets are the minerals: calcium, phosphorus, salt, iron, zinc, manganese, copper, iodine and selenium (in Illinois, Ohio, Indiana, and Michigan); and the vitamins: A, D, E, K (optional), riboflavin, niacin, pantothenic acid, vitamin B-12 and choline.

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Table 1. Amino Acid Needs of Swine (Percent of Diet)[a]

	Growing-finishing pigs						
Liveweight, lb.	11-22	22-44	44-77	77-132	132-220		
Expected daily gain, lb.	0.66	1.10	1.32	1.54	1.76	Bred gilts and sows; young and adult boars[b]	Lactating gilts and sows[c]
Expected feed/gain	1.67	2.00	2.50	2.86	3.75		
				Percent			
Crude protein[d]	20	18	16	14	13	12	14
Lysine	0.95	0.79	0.70	0.61	0.57	0.43	0.58
Methionine + cystine[e]	0.56	0.51	0 45	0.40	0.30	0.23	0.36
Tryptophan[f]	0.15	0.13	0.12	0.11	0.10	0.09	0.12
Threonine	0.56	0.51	0.45	0.39	0.37	0.34	0.43
Isoleucine	0.63	0.56	0.50	0.44	0.41	0.37	0.39
Valine	0.63	0.56	0.50	0.44	0.41	0.46	0.55[h]
Leucine	0.75	0.68	0.60	0.52	0.48	0.42	0.70[h]
Histidine	0.23	0.20	0.18	0.16	0.15	0.15	0.25[h]
Arginine	0.25	0.23	0.20	0.18	0.16	0	0.40[h]
Phenylalanine + tyrosine[g]	0.88	0.79	0.70	0.61	0.57	0.52[h]	0.85[h]

[a]Requirements reflect the estimated levels of each nutrient needed for optimal performance when a fortified corn-soybean meal diet is fed. Concentrations are based upon amounts per unit of air-dry diet (i.e., 90% dry matter).

[b]Bred gilts and sows should generally be fed 4 pounds of feed daily; gilts should gain about 65-70 pounds and sows 40 pounds during gestation (maternal gain); boars should be fed 4 to 5 pounds daily depending on condition. Requirements for boars have not been determined and, therefore, are assumed to be similar to those established for bred gilts and sows.

[c]Feed intake during lactation may be based upon the size of the litter nursed but generally falls in the range of 8 to 10 pounds for first-litter sows and 10-12 pounds for mature sows.

[d]Approximate protein levels needed to provide indispensable amino acids when a fortified corn-soybean meal diet is fed. With supplemental L-lysine·HCL, protein requirements can be lowered by 2 percentage units.

[e]Methionine can fulfill the total requirement; cystine can meet at least 50 percent of the total requirement.

[f]It is assumed that the usable tryptophan content of corn does not exceed 0.05 percent.

[g]Phenylalanine can fulfill the total requirement; tyrosine can meet at least 50 percent of the total requirement.

[h]These levels are adequate; the actual requirement has not been established.

Thus, knowing the requirements for individual amino acids at 16 percent protein for pigs weighing 44 to 77 pounds and knowing levels of protein (from corn-soybean meal mixtures) that will permit optimal performance in pigs at other stages of growth allows calculation (by linear extrapolation) of requirements for all weight ranges shown in Table 1. In most cases, requirements determined experimentally have been in close agreement with extrapolated values. An exception has been lysine for pigs weighing 11 to 22 pounds where determined requirements have been somewhat higher than those predicted by extrapolation. Also, the methionine + cystine requirement of swine weighing 132 to 220 pounds has been shown to be lower than that predicted by extrapolation. The levels shown in Table 1 are adequate to support normal growth and performance, and they apply to corn-soybean meal diets containing a metabolizable energy concentration of about 1450 kcal/pound.

The requirements for pregnant gilts and sows are based on amounts required for satisfactory retention of nitrogen during the late stages of pregnancy and are at least adequate to support development of a normal litter. Optimal levels have not been established.

The requirements for lactation either have been determined experimentally or have been extrapolated from published requirements for maintenance of adult female swine and from amounts calculated to be required to support good milk production. Corn-soybean meal diets containing 14 percent crude protein should provide adequate to superadequate intakes of all indispensable amino acids for swine lactation. Illinois researchers have compared 12, 14, 16 and 18 percent protein in a recent study. The results of that study suggest that no more than 14 percent dietary crude protein is needed for lactation of either first-litter gilts or second-litter sows. In fact, because only 13 percent protein is needed to meet the requirements for the first-limiting amino acid (ie., lysine), the 1979 N.R.C. Subcommittee on Swine Nutrition set the lactation crude protein requirement at 13 percent.

LYSINE SUPPLEMENTATION OF DIETS FOR GROWING-FINISHING SWINE

A long-term study comparing four regimens was recently conducted at the University of Illinois Swine Nutrition Farm. Quadruplicate groups of six pigs were assigned to one of the four feeding regimens outlined below.[2/]

Regimen	GROWER (50 to 105 lb.)	FINISHER I (105 to 165 lb.)	FINISHER II (165 to 205 lb.)
1	16% CP Control	13% CP Control	12% CP Control
2	14% CP + 0.14% Lysine	11.5% CP + 0.11% Lysine	11% CP + 0.08% Lysine
3	14% CP + 0.10% Lysine	11.5% CP + 0.08% Lysine	11% CP + 0.06% Lysine
4	14% CP Control	11.5% CP Control	11% CP Control

[2/]Lysine was provided as L-lysine·HCL (78.4% lysine). Regimen 2 called for lysine supplementation to bring diets to the same lysine concentration as that present in the control diet (Regimen 1) while Regimen 3 called for this same level less 0.02% for each 1% decrease in dietary protein level. All diets were fortified corn-soybean meal diets with 2% added meat and bone meal during the Grower Phase and 1% added meat and bone meal during both Finisher I and Finisher II.

As indicated in Table 2, performance of pigs fed diets in either Regimen 2 or 3 was equal to that of pigs fed the higher protein diets offered in Regimen 1. Regimens 1, 2, and 3 were clearly superior to Regimen 4, the low-protein regimen containing no supplemental lysine. Moreover, lean-cut yield was greater for pigs in Regimens 1, 2, and 3 than for those in Regimen 4. Thus, in agreement with earlier work from the Illinois Station, less total lysine is needed in lower protein diets containing crystalline lysine. The explanation for the lesser need for total lysine in lower protein diets containing synthetic lysine is twofold: (1) lysine fortified diets are better balanced in amino acid composition (ie., fewer excess amino acids) and (2) they contain more availabe (ie., digestible) lysine than that which exists in higher protein diets containing lysine from intact proteins only.

Table 2. Lysine Supplementation at Two Levels for Growing-Finishing Swine (Over-all Summary)[a]

Criterion	Regimen[b] 1	2	3	4
		Pounds		
Avg. daily gain				
Barrows	1.74	1.74	1.74	1.47
Gilts	1.54	1.56	1.53	1.34
Avg.[c]	1.64	1.65	1.64	1.41
Avg. gain/lb. of feed				
Barrows	0.29	0.30	0.30	0.26
Gilts	0.29	0.28	0.29	0.26
Avg.[d]	0.29	0.29	0.30	0.26

[a]Data represent means of two pens, each containing 6 pigs; avg. initial weight was 52 pounds; avg. final weight was 204 pounds.

[b]Regimens were continuous and consisted of a grower phase (50 to 105 lb.), an early finishing phase (105 to 165 lb.), and a late finishing phase (165 to 205 lb.). Regimen 1 was the normal protein series, Regimens 2 and 3 consisted of low protein diets containing either a high (Regimen 2) or low (Regimen 3) level of supplemental lysine, and Regimen 4 was the negative control low protein series containing no supplemental lysine.

[c]Treatment 4 was different ($P<.05$) from treatments 1, 2, and 3.

[d]Treatment 4 was different ($P<.10$) from treatments 1, 2, and 3.

Calcium and Phosphorus Requirements of Swine

E.R. PEO, JR.

The base line for calcium and phosphorus requirements of swine is generally accepted among nutritionists as that established by the Research Council of the National Academy of Sciences. The National Research Council (NRC) update their publication on nutrient requirements of swine periodically. The most recent update was in 1979.

As shown in Table 1, the NRC requirements for calcium and phosphorus vary slightly from what we recommend at Nebraska. The reasons for the differences are (1) the slight "cushion" we add to NRC requirements to cover a wide range of conditions that exist in the field, (2) our experience with levels of calcium and phosphorus that have worked well for swine producers, and (3) our interpretation of research on calcium and phosphorus requirements for swine, which differs from the interpretation of scientists who established the NRC requirements. Thus, our recommended levels of calcium and phosphorus for swine are called "allowances" as contrasted to the absolute *minimum* requirements established by NRC.

Phosphorus is a rather expensive mineral element to add to swine diets; calcium is cheap. Thus, quite often, swine diets approach or exceed the upper limits for calcium but just barely meet the minimum requirement for phosphorus. The consequences of feeding excess calcium with a minimum level of phosphorus, thereby creating a wide ratio between the two, are poor gains and feed conversion and structural unsoundness. Swine can perform reasonably well on high levels of calcium in the diet as long as a desirable ratio exists between calcium and phosphorus.

Table 1. Calcium-Phosphorus Requirements of Swine

	NRC requirements		Nebraska allowances	
Pig wt., lb.	Calcium	Phosphorus	Calcium	Phosphorus
	Percent of diet			
2 - 10	0.90	0.70	0.90	0.80
10 - 20	0.80	0.60	0.80	0.70
20 - 45	0.65	0.55	0.65	0.50
45 - 75	0.60	0.50	0.65	0.50
75 - 130	0.55	0.45	0.65	0.50
130 - 220	0.50	0.40	0.65	0.50
Breeding stock[a]				
Gestation	0.75	0.60	0.90	0.80
Lactation	0.75	0.50	0.90	0.80
Young and adult boars	0.75	0.60	0.90	0.80

[a]Assumes 4.0 lbs./head/day of a corn-soybean meal diet.

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The optimum ratio appears to lie between 1 and 1.3 to 1 with outside limits of 0.9 and 1.6 to 1 (Combs *et al.*, 1962; Peo, 1976; Hays, 1975' Henika, 1978). During the early part of this century, the recommended ratio of calcium to phosphorus was higher than the optimum. At that time rickets (faulty bone formation) was commonly seen in swine. Analysis of bone (Table 2) showed that it contained Ca and P in about a 2:1 ratio. Since grain contains very little calcium, the general recommendation at that time was to feed diets or mineral with a Ca:P ratio similar to that found in bone. Recent reviews by Peo (1976) and Hays (1976) on the role of calcium and phosphorus in swine nutrition certainly point out the fallacy of thinking that the ratio of Ca:P in bone is the ratio that should be in the feed. A more appropriate indicator is probably the composition of sow's milk (Table 3). The Ca:P ratio in sow's milk varies from 0.6 to 1.2:1. "You can't fool mother nature" is a rather true statement when one thinks about the purpose of sow's milk--to provide those nutrients needed for development of a young growing animal. If calcium and phosphorus were needed in a 2:1 ratio to optimize bone mineralization, it is logical to assume that the two elements would have been present in that ratio in milk.

Table 2. Composition of Bone Ash

	Pct.
Calcium	36
Phosphorus	17
Magnesium	0.8
Ca:P ratio	2.1:1

Table 3. Composition of Sow's Milk
(Fahmy and Bernard, 1971)

	Day			
	1	14	28	35
Ca, pct.	.05	.25	.15	.18
P, pct.	.09	.22	.14	.15
Ca:P ratio	0.6:1	1.14:1	1.07:1	1.2:1

Pigs fed varying levels of calcium and phosphorus respond in terms of gains, bone weight, or bone breaking strength according to the ratio of Ca and P fed. The research data presented in Table 4 show that at 0.3 percent P (all of plant origin) average daily gain decreased as level of calcium increased in the diet--a response reflecting a widening calcium-phosphorus ratio. Gains were similar across all three levels of calcium when 0.5 percent P was fed and increased when 0.7 percent P was fed. The greatest average daily gain was obtained with 0.9 percent calcium and 0.7 percent phosphorus, an ideal ratio. Similar results were obtained for weight and breaking strength of bones from the test animals (Table 5 and 6). The importance of Ca:P ratio for swine cannot be emphasized enough.

Table 4. Ca-P Levels for Growing-Finishing Swine
(Peo, 1967)

	Ca levels, pct.			
P, pct.	0.35	0.65	0.90	Average for P[a]
	Average daily gain, lb.			Lb.
0.30	1.52	1.46	1.18	1.39
0.50	1.66	1.66	1.56	1.62
0.70	1.52	1.64	1.70	1.63
Average for Ca[b]	1.57	1.59	1.48	

[a] Linear and quadratic effect of P level ($P<.005$).
[b] Linear effect of Ca level ($P<.05$); Ca x P interaction ($P<.005$).

Table 5. Ca-P Levels for Growing-Finishing Swine
(Peo, 1967)

P, pct.	Ca levels, pct. 0.35	0.65	0.90	Average for P[a]
	Bone weight, gm.[b]			gm.
0.30	11.4	12.8	11.3	11.8
0.50	13.4	14.1	15.4	14.3
0.70	12.1	14.2	14.9	13.7
Average for Ca[c]	12.3	13.7	13.8	

[a]Linear and quadratic effect of P level (P<.025).
[b]Weight of moisture, fat-free 4th metatarsal.
[c]Linear effect of Ca level (P<.05).

Table 6. Ca-P Levels for Growing-Finishing Swine
(Peo, 1967)

P, pct.	Ca levels, pct. 0.35	0.65	0.90	Average for P[a]
	Bone strength, kg.[b]			
0.30	201	237	209	216
0.50	193	307	368	289
0.70	152	283	349	261
Average for Ca[c]	182	276	309	

[a]Quadratic effect of P level (P<.05).
[b]Breaking strength of moisture, fat-free 4th metatarsal.
[c]Linear effect of Ca level (P<.005).

Another problem associated with meeting the calcium-phosphorus requirements of swine is the amount of plant (phytin) phosphorus in the diet. In a typical corn-soybean meal diet, this amounts to about 0.3 percent P, of which only 20-40 percent is available to the pig (Cromwell, 1979). Libal *et al.* (1969) showed that gains, feed intake, and bone breaking strength increased in a linear manner as percentage of inorganic phosphorus (from monosodium phosphate) increased in the diet. The results of their research are shown in Table. 7

The importance of having an adequate level of available phosphorus in the diet of swine is evident from the research by Libal *et al.* (1960). However, it is difficult to predict on a routine basis how much of the phosphorus in an all-plant diet is available to swine. As indicated earlier, Cromwell has suggested that the availability of P in cereal grains varies from 20 to 40 percent. Hays reports values from as low as 1.9 percent in grain sorghum to as high as 60 percent in a corn-soybean meal diet. Because of the uncertainty about the biological availability of plant phosphorus, we prefer to express requirements on the basis of total phosphorus in the diet. Since most swine diets today are largely formulated with plant feedstuffs (grain-soybean meal), our recommended allowances for swine shown in Table 1 will force an extra increment of inorganic phosphorus into the diet as insurance against the high variability in the biological availability of phosphorus from plant sources.

Table 7. Effect of Levels of Inorganic Phosphorus on Gain, Feed Conversion, and Bone Characteristics of Growing-Finishing Swine
(Libal *et al.*, 1969)

	Treatments[a]				
Ca, pct.	0.35	0.35	0.35	0.35	0.35
P, pct.	0.30	0.40	0.50	0.60	0.70
Inorganic P, pct. of total	0	25	40	50	57
Avg. daily gain, lb.[b]	1.41	1.47	1.52	1.58	1.54
Feed intake, lb.[c]	4.80	4.95	5.26	5.48	5.32
Feed/gain ratio	3.44	3.33	3.57	3.44	3.45
Bone characteristics					
Breaking strength, kg.[d]	165	258	209	267	245
Bone wt., gm.	9.9	12.3	12.0	12.4	11.8
Bone ash, pct.	57.4	59.1	58.7	58.5	58.9

[a]Data based on 2 pens of 6 pigs pen/treatment. Initial wt 54 lbs.
[b]Linear effect of P levels (P<.10).
[c]Linear effect of P levels (P<.005).
[d]Force; overall treatment effect (P<.05); linear effect of P levels (P<.10).

Perhaps the most critical problem facing the swine producer today is trying to satisfy the calcium-phosphorus requirements of breeding stock, particularly gestating and lactating swine. The main reason for the problem is the lack of research on calcium and phosphorus requirements for this class of swine. The 1979 NRC requirements for the two elements seem to be too low. Kornegay *et al.* (1973) fed two levels of calcium and phosphorus to gilts carried through five reproductive cycles. The results of their research are shown in Table 8. Only 56 percent of the gilts on the low level of calcium and phosphorus completed five cycles as compared to 70 percent of those on the high levels. The low levels fed by Kornegay *et al.* were less than the 1979 NRC daily requirements for calcium but were equal to NRC's level for phosphorus. Harmon *et al.* (1975) found that farrowing performance was improved in sows fed 12.4 grams of phosphorus per day compared to those fed 6.0 grams. Lactation performance was better with sows fed 16.5 grams of phosphorus per day as compared to those fed 13.5 grams (Tables 9 and 10). The NRC requirement of 10.7 grams of phosphorus per day for breeding stock during gestation is probably satisfactory if diet phosphorus is 100 percent available. Nebraska's allowance of 14.5 grams of phosphorus per day during gestation, while apparently high, takes into consideration that not all of the phosphorus in a brood sow diet is available. If we assume that about 75 percent of the 14.5 grams is available (this should be close), then phosphorus uptake by the body is only 10.8 grams--an amount equal to the NRC requirement. We also recommend a daily intake of 16.3 grams of calcium. Our levels of 0.9 percent calcium and 0.8 percent phosphorus are the recommended daily allowances for the two elements *if* the swine producer is feeding 4 pounds/head/day. Changes in feeding rate will require changes in percentages of calcium and phosphorus in the diet to satisfy daily requirements (Figure 1).

As stated earlier, research on the calcium-phosphorus requirements of brood sows is limited. With the boar it is practically nonexistent. The reason is quite simple. Boar research is too expensive for experiment stations whose budgets are heavily dependent upon sales of research animals. Too much money is lost on boars

at the marketplace as compared to barrows and gilts. However, a few brave souls have embarked upon some research that should provide us with good recommendations as regards the calcium and phosphorus requirements of boars.

Table 8. Calcium-Phosphorus Levels for Gestating Swine
(Kornegay *et al.*, 1973)

Criterion	Level of intake 10.3 gm. Ca 11.0 gm. P	 15.5 gm. Ca 15.0 gm. P
No. gilts started	55	54
No. gilts finished[a]	31	38
Pct. finished	56	70
No. litters	182	216
Live pigs/litter	10.0	10.2
Dead pigs/litter	0.66	0.59
Avg. birth wt., lb.	3.2	3.2
Avg. no. weaned/litter	7.3	7.4
Avg. weaning wt., lb.	25	24

[a]Five reproductive cycles. Six sows eliminated from low Ca and P and three from high Ca and P as cripples.

Table 9. Effect of Different Phosphorus Levels During Pregnancy
(Harmon *et al.*, 1975)

Phosphorus, diet pct.	0.33	0.68
Daily intake, gm.	6.0	12.4
No. pigs born	8.9	9.2
Live pigs born	7.9	8.4
Litter wt., kg.	11.1	13.0
Lactation performance[a]		
No. pigs weaned	7.2	7.2
Litter gain, kg. (28 days)	31.5	28.2
Milk yield/day, kg.	2.60	2.82
Phosphorus balance during lactation		
P intake/day,gm.	16.5	16.5
P absorbed/day, gm.	6.9	6.6
P retained/day, gm.	6.2	6.0
Milk P/day, gm.	3.9	4.1
P balance/day, gm.	2.1	1.1
P error/day, gm.	0.2	0.8
Bone composition		
Ash, pct.		
Rib	58.4	58.8
Turbinate	57.0	58.1

[a]Three levels of phosphorus fed each group during lactation.

Table 10. Effect of Different Levels of Phosphorus During Lactation (Harmon *et al.*, 1975)

Phosphorus, diet pct.[a]	0.45	0.55	0.65
Daily intake, gm.	13.5	16.5	19.5
Lactation performance			
No. pigs weaned	7.45	7.35	6.90
Litter gain, kg.	30.3	32.8	26.6
Milk yield/day, kg.	2.55	2.95	2.62
Phosphorus balance			
P intake/day, gm.	13.5	16.5	19.5
P absorbed/day, gm.	4.7	6.9	8.9
P retained/day, gm.	4.6	6.4	7.5
Milk P/day, gm.	3.8	4.4	3.8
P balance/day, gm.	0.8	1.5	2.8
P error/day, gm.	0.0	0.5	0.9
Bone composition			
Ash, pct.			
Rib	57.3	59.0	59.4
Turbinate	56.2	58.1	58.4

[a]Pregnancy phosphorus levels were either 0.33 or 0.68 percent P. Assumed an equal number on each treatment.

Tanksley (1974) reported that dietary calcium and phosphorus requirements are higher for maximum bone development than for gain or feed efficiency of developing boars. It has been postulated that boars grow faster and convert feed more efficiently than barrows and gilts. Therefore the calcium-phosphorus requirements of boars must be higher than those of barrows and gilts if problems with structural unsoundness in boars are to be reduced. Boars probably do grow faster than barrows and gilts when considered over the age period from weaning to 250 pounds. However, data from research by Crenshaw (1979) at the Nebraska Station indicate that boars, barrows, and gilts grow at about the same rate up to 125 pounds before they start to separate as regards growth rate. If this is true, then it would seem that calcium-phosphorus requirements would be similar among the three. McMeekan's work would also suggest that rate of skeletal growth is rather constant up to maturity (see Figure 2). Thus one might speculate that calcium-phosphorus requirements could be different depending not only on age and sex but also on rate of deposition of muscle and fat in the body. If skeletal growth is relatively constant or increases slightly with age, perhaps calcium and phosphorus requirements of boars should be high late in the growth period or at least held constant (assuming higher dietary requirements for young animals) throughout growth in order to maximize skeletal development for support of greater soft tissue (muscle) growth in boars than in barrows and gilts.

Research by Nimmo (1978) helps answer some of the above questions. He fed growing boars (3-19 weeks of age) 17 percent protein diets varying in calcium and phosphorus.

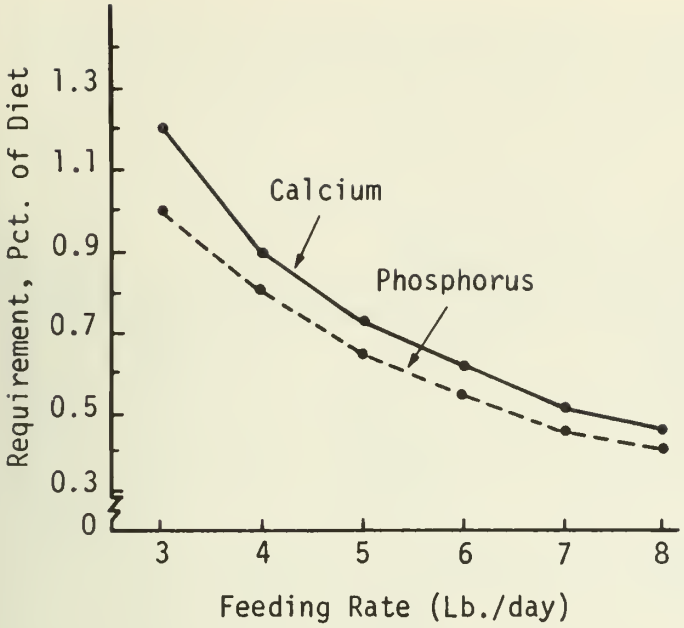


Figure 1. Relation of level of feeding to meeting daily Ca-P requirements of bred sows.

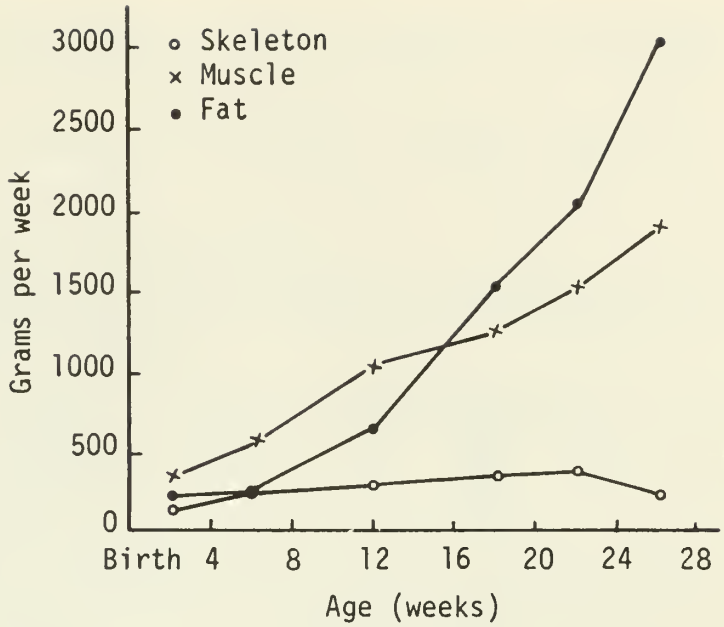


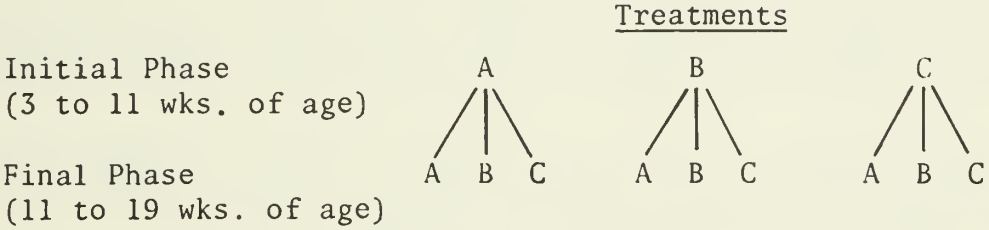
Figure 2. Rate of growth of skeleton, muscle, fat with age in swine. (McMeekan)

The treatments were:

A -- .65% Ca; .50% P
B -- .975% Ca; .75% P
C -- 1.30% Ca; 1.0% P

At 11 weeks of age, the boars were split and fed according to the following schedule:

Feeding Schedule



As shown in Table 11, average daily gain, average daily feed intake and feed/gain ratio did not differ among the boars fed the various treatment combinations. However, there were marked differences in bone development in the boars. In general, boars that had been fed diets B or C early in life (3 weeks to 11 weeks of age) had stronger bones than those fed diet A. Switching boars from diet A to diets B and C after 11 weeks did not offset the effects of feeding the low levels of calcium and phosphorus (diet A) early. It should be painted out that diet A (.65 percent Ca and .50 percent P) was considered to be adequate in calcium and phosphorus for growing swine. As far as gain and feed conversion are concerned, it was; for maximum bone mineralization it was not. Structural abnormalities developed in some of the boars fed diet A. The results of Nimmo's research agree in general with the conclusion of Tanksley -- that levels of dietary calcium and

phosphorus needed to maximize bone formation in developing swine are higher than levels required for optimum gains and feed conversion. Thus, the 0.9 percent Ca and 0.8 percent P recommended for gilts and sows should meet the requirement for these two elements for developing boars.

Table 11. Effect of Levels of Calcium and Phosphorus on Gain, Feed Conversion and Bone Strength of Boars
(Nimmo, 1978)

Diet schedule[a]	Avg. daily gain (kg.)	F/G	BKS[b] (kg.)
AA	1.58	2.48	227
BB	1.63	2.57	254
CC	1.58	2.50	259
AB	1.58	2.48	253
AC	1.58	2.67	229
BA	1.58	2.69	241
BC	1.65	2.65	262
CA	1.61	2.52	232
CB	1.56	2.56	271

[a]First letter indicates diet fed from 3 to 11 weeks of age; second letter indicates diet fed 11 to 19 weeks of age. Diet A = .65% Ca, .50% P; Diet B = .975% Ca, .75% P; Diet C = 1.30% Ca, 1.0% P.
[b]Average composite breaking strength of the femur, 3rd and 4th metatarsals.

In conclusion, it should be reemphasized that calcium and phosphorus are inseparable when considering their requirements. The golden rule to follow in swine diet formulations is "whatever is done with calcium levels, do the same thing with phosphorus." That is, the two should go up or down together in diets to maintain an optimum ratio between them. If for some reason calcium is increased in the diet 0.1 percent (or 0.2 or 0.3 or 0.4 percent) then phosphorus should be increased 0.1 percent (or 0.2 or 0.3 or 0.4 percent) too.

At today's prices, it will cost about $1.00/ton of feed to add 0.1 percent phosphorus. This seems a small price to pay for the opportunity for improved performance and perhaps less structural unsoundness in swine.

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Vitamin Needs in Swine Nutrition

ROBERT A. EASTER AND DAVID H. BAKER

Vitamins are organic molecules essential to cellular metabolism. In most instances their basic biochemical roles have been clearly established. Unfortunately, vitamin nutrition is often poorly understood to the point that vitamin therapy may be looked upon as a cure for a host of real and imagined ills.

Vitamins are classified according to solubility characteristics. Vitamins A, D, E and K are lipid soluble and are thus referred to as the fat soluble vitamins. Ascorbic acid and the B-complex vitamins are water soluble.

Although each vitamin must be present in the pig's cells to maintain normal cellular function, not all vitamins need to be added to practical diets. Three factors account for this: (1) Some vitamins can be made by the pig in sufficient quantity to meet requirements. Ascorbic acid, or vitamin C, is a good example. (2) The large microbial population in the gastrointestinal tract is a source of vitamins. Enough biotin, for example, is produced by the gut microbes to meet the normal demand for this vitamin. (3) Finally, several vitamins are present in sufficient quantity in grain-soy diets to meet requirements. It is generally accepted today that the corn-soy diet should be supplemented with Vitamins A, D, E, and K; riboflavin, niacin, pantothenic acid, choline, and vitamin B-12.

The clinical or visible signs of vitamin deficiencies in swine are summararized in Table 1. Unfortunately, clinically evident signs are rarely sufficient to establish a clear diagnosis of a vitamin deficiency. Take riboflavin deficiency as an example. Insufficient riboflavin intake during gestation results in stillborn pigs with multiple birth defects. Several other nutritional and disease conditions will produce the same effects; thus a correct diagnosis is almost impossible on the basis of visible signs alone. These signs considered in conjunction with a general knowledge of conditions likely to precipitate a deficiency, however, can provide a working assessment of the problem.

VITAMINS OF SPECIFIC INTEREST IN SWINE NUTRITION

The following discussion focuses on aspects of specific vitamins that are useful in practical feeding situations.

Vitamin A. Fred Hale (1934) at the Texas Station first observed the teratogenic effects of vitamin A deficiency in swine. In his study the deficiency of vitamin A during gestation resulted in multiple birth defects (malformed eyes, cleft palates and misplaced kidneys). Others have reported depressed thyroid function and impaired antibody response in addition to the classical visual impairment resulting from vitamin A deficiency in growing-finishing pigs.

Vitamin A in plant sources occurs as the yellow carotenoid pigments, of which the principal one is β-carotene. The β-carotene is hydrolyzed by gut-wall enzymes to yield one molecule of vitamin A per molecule of β-carotene. Yellow corn is richer in carotene than white corn, which contains very little carotenoid pigments. It was common knowledge among hog farmers at the turn of the century that

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pigs fed white corn in drylots gained less well than pigs fed yellow corn. We now know that the difference was due to a vitamin A deficiency in white corn.

Table 1. Signs of Vitamin Deficiencies

Vitamin	Signs of deficiency	
	Clinical	Subclinical
Vitamin A	Incoordination Lordosis Paralysis of rear limbs Night blindness Congenital defects	Retarded bone growth Increase in cerebrospinal fluid pressure Degeneration of sciatic and femoral nerves Minimal visual purple Atrophy of epithelial layers of genital tract
Vitamin D	Ricketts Osteomalacia Low calcium tetany	Lack of bone calcification Proliferation of epiphyseal cartilage Rib and vertebra fracture Low plasma calcium, magnesium and inorganic phosphorus levels Elevated serum alkaline phosphatase levels
Vitamin E-Selenium	Edema Sudden death	Generalized edema Liver necreosis (hepatosis dietetica) Cardiac muscle degeneration (mulberry heart) Pale, dystrophic muscle
Vitamin K	Pale newborn pigs with loss of blood from umbilical cord Sudden death following dicoumarin intake	Increased prothrombin time Increased blood clotting time Internal hemorrhage Anemia due to blood loss
Thiamin	Poor appetite Poor growth Sudden death	Cardiac hypertrophy Bradycardia First and second degree auriculoventricular block Elevated plasma pyruvate
Riboflavin	Slow growth Seborrhea Impaired sow reproductivity	Lens cataracts Increase in neutrophilic leukocytes Birth of weak pigs with skeletal anomalies
Niacin	Poor appetite Poor growth Severe diarrhea Dermatitis	Necrotic lesions of intestine

Concluded on next page.

Table 1 (concluded)

Vitamin	Signs of deficiency	
	Clinical	Subclinical
Pantothenic acid	Poor appetite Poor growth Diarrhea Unusual gait (goose stepping) Impaired sow reproduction	Inflammation of colon Degeneration of sciatic and peripheral nerves Reduced blood pantothenic level Reduced milk free-pantothenic acid level
Pyridoxine (B-6)	Poor growth Epileptic seizures	Microcytic hypochromic anemia Elevated serum iron Fatty infiltration of liver Elevated urinary xanthurenic acid Elevated gamma globulin-like blood protein fraction
B-12	Depressed growth Hypersensitivity Reduced sow reproductivity	Reduced serum and tissue B-12 levels
Choline	Slow growth Reduced litter size	Fatty infiltration of liver Reduced conception rate
Biotin	Dermatosis Spasticity of hind legs	Reduced urinary biotin excretion
Folic acid	Poor growth Weakness	Normocytic anemia

Vitamin A is often associated with vision, but it is important to other body functions as well. The mucus membranes that protect the respiratory, gastrointestinal and urogenital tracts are dependent on vitamin A for normal function. A deficiency results in a breakdown in the integrity of these membranes and thus an opportunity for bacterial invasion and disease. Vitamin A is also important in reproduction and bone development.

Although corn is a relatively rich cereal source of carotene for Vitamin A synthesis, there is evidence (McDonald *et al.* 1966) that pig performance is improved with supplemental A. Other grains, such as wheat, are much lower in vitamin A, and supplementation is of obvious benefit when diets are formulated with these grains. Pure vitamin A is susceptible to oxidative damage when mixed in diets; thus protected forms of the vitamin—vitamin A acetate or vitamin A palmitate, for example—should always be used.

As a matter of convenience vitamin A requirements are generally expressed in "units of vitamin A activity." One international unit (IU) of vitamin A activity is equivalent to 0.300 µg of crystalline vitamin A alcohol, 0.344 µg of vitamin A acetate or 0.550 µg of vitamin A palmitate.

Vitamin D. Vitamin D occurs in nature in both plant material and animal tissue. In either case irradiation of the parent compound (ergosterol in plants or 7-dehyrocholesterol in animals) by the ultraviolet portion of sunlight is essential to the formation of the active vitamin. In animals the irradiation occurs by exposure of the skin to direct sunlight, thus pigs exposed to sunlight daily can do quite well without supplemental vitamin D. Grain-soy diets are low in vitamin D and pigs reared in modern confinement buildings must have vitamin D added to the diet. Supplemental vitamin D is available either as D_2, from ergosterol, or D_3, from 7-dehydrocholesterol. Swine can readily utilize either form; avian species can use only D_3.

Recent discoveries have greatly enhanced our understanding of the role of vitamin D in calcium metabolism. Irradiated vitamin D is changed by enzymes in the liver and kidney to a form that ultimately exerts a hormone-like effect on the cells lining the small intestine. The cells are stimulated to produce a calcium-binding protein that causes calcium to be absorbed from the small intestine. Calcium absorption is impaired in a vitamin D deficiency and the familiar weak bone condition commonly known as rickets develops in growing pigs. Mature boars and sows suffer demineralization of bone and a resultant increase in bone fractures.

There has been a trend in recent years to suggest that extra vitamin D might be used to overcome feet and leg maladies in boars and sows. There is no evidence that exceeding the established vitamin D requirement is beneficial to the pig. In fact, one would be well advised to avoid "shotgun" therapy with vitamin D as excesses can lead to hypercalcemia, anorexia, kidney and arterial calcification, and death. The danger of excessive D is underscored by the fact that high-potency preparations of the vitamin are being marketed in Europe as rat posion.

Vitamin E. Vitamin E is the general name for a family of compounds known as the tocopherols, of which alpha tocopherol is the most prominent. The functions of vitamin E in the body have not been clearly established. This situation has led to a host of unfounded claims of vitamin E benefits, particularly in humans.

Vitamin E does have a clear role as a cellular antioxidant to prevent the formation of peroxides. Peroxides lead to destruction of cellular membranes and in severe cases piglet death. Vitamin E is closely associated with selenium in a "two-stage" control of peroxides in the cell. If peroxides occur they can be broken down by the cellular enzyme, glutathione peroxidase. Gluthathione peroxidase requires four atoms of selenium in order to function. In a vitamin E deficiency, peroxides would be destroyed if selenium were adequate. In a selenium deficiency peroxide formation would be prevented provided vitamin E was adequate. Thus, when selenium is not adequate in the diet, vitamin E will alleviate the sudden death syndrome associated with selenium deficiency.

Because of early rat research, vitamin E has gained the reputation of being an antisterility vitamin. There is no evidence that the reproductive performance of either boars or sows is enhanced by large doses of vitamin E

Vitamin K. This vitamin derives its name from the Danish word for coagulation, which indicates the role of vitamin K in the blood clotting process. It has generally been accepted that gut synthesis and dietary sources of vitamin K amply meet the pig's requirement. The problem of mycotoxicosis or "moldy corn" has caused a change in this perspective. The data in Table 2 provide a good example of the importance of adequate vitamin K when diets are contaminated with mold. When the suspect (mold-contaminated) diet, was fed for nine days, blood-clotting time increased three-fold. At this point simple injury would result in terminal hemorrhage.

Note that the addition of either alfalfa, rich in vitamin K, or the actual vitamin greatly alleviated this problem. Because moldy grain is frequently undetected before a major problem develops, many nutritionists today recommend the routine supplementation of swine diets with vitamin K as a prophylactic measure.

Table 2. Vitamin K in Nutritionally Induced Hemophilia in Swine[a]

Dietary treatment	Mean blood clotting time, minutes	
	Initial	Final
1. Suspect diet	3.04	10.43
2. As 1 + 2.5% alfalfa meal	3.20	5.08
3. As 1 + 2 gm./ton vitamin K	3.31	4.11

[a]Fritschen *et al.* 1970.

A number of compounds exhibit vitamin K activity, of which the most commonly used is menadione. Commercial menadione is marketed in the three chemical forms shown in Table 3. Also indicated in this table is the percentage concentration of actual menadione in each compound.

Table 3. Sources of Menadione (Synthetic K)[a]

Source	Percent menadione
Menadione sodium bisulfite	50
Menadione dimethyl pyrimidinol bisulfite	45.4
Menadione sodium bisulfite complex	33

[a]Also called vitamin K-3.

Riboflavin. Riboflavin is a B-complex vitamin well known for its intense yellow color. Metabolically, riboflavin functions in energy metabolism and the daily requirement is increased in periods of cold stress, when metabolic rate is accelerated. This is not of practical concern to the swine producer as recommended levels include an allowance for the greater need during cold months.

Riboflavin deficiency results in deficiency signs common to many disorders, such as hair loss and reduced growth rate, in growing pigs. The effect in pregnancy is much more dramatic in that deficient sows farrow dead pigs. Typically, all pigs are hairless, about one-third are mummies, and the remainder appear to be stillborn.

Corn-soy diets contain from 1.2 to 1.5 mg./kg. of total riboflavin. The limited research data that are available indicate that this amount is insufficient for growth and reproduction. The actual requirements are ill-defined and most supplemented diets probably contain much more than is needed. We have recently developed a simple blood test for riboflavin status in pigs. The test is based on the activity of a riboflavin-dependent enzyme, glutathione reductase, in the pig's red blood cells. As shown in Table 4, a riboflavin deficiency results in a significant increase in the glutathione reductase ratio value. This test is the basis of our current experiments to determine the riboflavin requirement of the gestating sow.

Riboflavin is unstable in light and there is a loss, though highly variable, of riboflavin activity when feed is exposed to direct sunlight.

Table 4. Effect of Riboflavin Deficiency on Red Blood Cell Glutathionine Reductase Activity in Post-Pubertal Gilts[a]

Treatment	Dietary riboflavin, mg./kg.	Days on test				
		0	28	56	84	110
		Glutathione reductase ratio				
With added riboflavin	8.03	1.37	1.45	1.45	1.47	1.48
Without added riboflavin	.77	1.41	1.89	2.02	2.16	2.27

[a]Esch *et al.* 1979.

Niacin. Niacin is the general name for compounds exhibiting the nutritional activity of nicotinic acid. Although grain diets contain appreciable niacin and nicotinic acid can be made metabolically from the amino acid tryptophan, it is generally desirable to add crystalline nicotinc acid to swine diets. There are two major reasons for the addition. Niacin in grain is largely unavailable unless the grain is processed by alkaline methods. Secondly, corn is particularly deficient in tryptophan, and the quantity of tryptophan that can be converted to nicotinic acid is limited. Pigs fed a niacin-deficient diet tend to develop anorexia, exhibit poor growth, and suffer from necrotic diarrhea.

In addition to nicotinic acid, niacin is also sold as niacinamide. Although the niacinamide molecule possesses a potentially reactive amino group, the product appears to be stable in feeds.

Pantothenic Acid. This vitamin is widely distributed in feed ingredients of plant and animal origin. Early research data indicated a clear need for supplemental pantothenic acid to prevent deficiency signs and maintain optimal growth when pigs were fed practical diets. More recent data from the Minnesota Station (Table 5) do not support the addition of pantothenic acid to starter diets formulated with corn and soybean meal. Similar negative findings have been reported by Pond *et al.* (1960) for growing and finishing pigs with the same type of diet. Nonetheless, pantothenic acid is routinely added to swine diets because of a clear need for supplemental pantothenic acid in reproduction (Davey and Stevenson, 1963) and a lack of information regarding diets formulated with ingredients other than corn and soybean meal.

Table 5. Influence of Pantothenic Acid Supplementation of Corn-Soybean Meal Diets on Rate and Efficiency of Gain of Young Pigs[a]

Response criterion	Pantothenic acid added, mg./kg.[b]				
	0	2.02	4.05	6.07	8.09
Avg. daily gain, kg.	.43	.43	.42	.43	.43
Feed/gain	2.08	2.04	2.07	2.04	2.02

[a]Palm *et al.* 1968.
[b]Basal diet was formulated with corn and soybean meal.

Because pantothenic acid is needed for proper nerve function, pigs deficient in this vitamin develop locomotor incoordination. This is particularly evident in pigs born to sows deficient in pantothenic acid. The condition produces a peculiar gait popularly referred to as goose-stepping.

The usual commercial source of pantothenic acid is the calcium salt. Calcium pantothenate is commonly a racemic mixture of the "d" and "l" isomers with only the "d" isomer possessing biological activity for the pig.

Vitamin B-12. Cyanocobalamin or vitamin B-12 is found in nature only as a result of microbial synthesis; thus plant materials are devoid of B-12 unless contaminated with microbes. This may occur as a result of using fecal material (a rich B-12 source) for fertilizer.

Although required only in minute amounts, supplemental B-12 is absolutely essential in the grain-soybean meal diet. Before the introduction of commerical B-12 in the early 1950's it was necessary to include animal by-products in swine diets as a source of this essential vitamin.

A B-12 deficiency is characterized by anemia and poor growth. A long-term deficiency produces diffuse and progressive nerve degeneration.

Choline. Unlike the other vitamins, choline is a structural component of tissue rather than a simple cofactor in metabolic reactions. Choline can be synthesized by the pig. However, because the synthesis depends on metabolites that may be in short supply, a dietary requirement can easily be demonstrated with purified diets. Soybean meal is a relatively good source of choline and a recent cooperative study at several midwestern experiment stations demonstrated that the corn-soy diet does not require supplemental choline for starter, grower, and finisher pigs. Gestation is a different case. The data in Table 6 provide good evidence that supplemental choline improves litter size at birth and at 2 weeks of age. The quantitative choline requirement for gestation is not well defined at present.

Table 6. Effect of Supplemental Choline on Reproductive Performance of Sows Fed a Corn-Soybean Meal Diet During Gestation[a]

Criterion	No added choline	With added choline[b]
Total pigs farrowed	9.89	10.54
Pigs born alive	8.64	9.33
Pigs alive at 2 weeks	7.29	7.72
Average live pig birth wt., gm.	1383	1359
Average pig wt. at 2 weeks, gm.	3917	3886

[a]NCR-42. 1976.
[b]770 mg. of choline added per kg. of diet in both gestation and lactation.

Several investigators have associated choline with the spraddle-leg condition seen in some pigs at birth. There was an attempt in the multi-station cooperative experiment shown in Table 6 to measure the effect of choline on the occurrence of spraddle-leg pigs. The data are shown in Table 7. Only four of the nine cooperating stations reported any spraddle-leg pigs. Most of these occurred at one station and there appeared to be a beneficial effect due to choline. This finding suggests that the spraddle-leg condition may involve the environment (floor material), genetic background, and choline.

Table 7. Effect of Choline on the Spraddle-leg Condition in New Born Pigs[a]

Station	Total litters	Total no. of spraddle-leg pigs	
		No added choline	With added choline[b]
3	111	3	3
6	66	4	5
7	69	0	1
9	38	35	20
Total		42	29

[a]NCR-42. 1976.
[b]770 mg. of choline added per kg. of diet in both gestation and lactation.

Biotin, Vitamin B-6, Thiamin and Folacin. Traditionally, these four vitamins have not been added to practical diets. Microbial synthesis along with the quantity naturally present in feedstuffs has been thought adequate to meet metabolic needs. Because of recent interest in these vitamins we have conducted a series of studies in which we added each of them individually to starter, grower, finisher, and gestation diets formulated with corn and soybean meal. The data in Table 8 clearly indicate a lack of response to addition of either biotin or pyridoxine to diets for growing-finishing swine. Similar negative results were obtained with both thiamin and folacin (Table 9).

Table 8. Performance of Starter and Growing/Finishing Fed Biotin Or Pyridoxine Supplemented Diets

Criterion	Diets			
	Control	0.2 ppm biotin	3.0 ppm pyridoxine	Pooled std. error
Starter phase[a]				
Average daily gain, kg.	.57	.54	.57	.012
Average daily feed, kg.	1.16	1.13	1.17	.026
Gain/feed ratio	.49	.48	.49	.028
Growing/finishing phase[a]				
Average daily gain, kg.	.76	.74	.75	.017
Average daily feed, kg.	2.50	2.31	2.49	.078
Gain/feed ratio	.30	.31	.30	.006

[a]Average initial weights were 12 kg. and 29 kg., respectively, for the starter and growing/finishing phases. Pigs averaged 91 kg. at the end of the experiment. There were 6 pens per treatment (5 pigs/pen) in the starter phase and 3 pens per treatment (10 pigs/pen) in the growing/finishing phase.

Table 9. Performance of Starter and Growing/Finishing Pigs Fed Folacin or Thiamine Supplemented Diets

Criterion	Diets			
	Control	0.5 ppm biotin	3.0 ppm thiamine	Pooled std. error
Starter phase[a,b]				
Average daily gain, kg.	.46	.47	.48	.02
Growing/finishing phase[a]				
Average daily gain, kg.	.73	.75	.75	.02
Average daily feed, kg.	2.36	2.59	2.47	.03
Gain/feed ratio	.31	.30	.30	.01

[a]Average initial weights were 9.0 kg. and 22.7 kg., respectively, for the starter and growing/finishing phases. Pigs averaged 97.8 kg. at the conclusion of the experiment. There were 6 pens per treatment (5 pigs/pen) in the starter phase and 3 pens per treatment (10 pigs/pen) in the growing/finishing phase.
[b]Because an error was suspected in the measurement of feed consumption during the starter phase, average daily feed and gain/feed ratio are not presented for this phase.

A similar experiment was conducted with gestating gilts using a corn-soy diet. The gilts were housed in total confinement and fed 1.9 kg. of diet per day. The results are shown in Table 10. There was a significant improvement in litter size with B-6 addition and an increase in gestation weight gain with folacin addition. Additional research is underway to determine if the response can be repeated.

Table 10. Reproductive Performance of Gilts Fed Biotin, Phyridoxine, Folacin, and Thiamine Supplemented Diets During Gestation[a]

Criterion	Vitamin addition to 12% corn-soy diet					
	Control	0.2 ppm biotin	1.0 ppm pyri-doxine	0.2 ppm folacin	1.0 ppm thia-mine	Pooled std. error
No. data	19	23	22	23	22	
Pigs born/litter	9.0	10.0	10.6	9.6	9.7	.57
Pigs born alive/litter	8.5	9.2	9.7	8.8	8.6	.47
Pigs weaned/litter	7.4	8.5	8.7	7.9	7.9	.44
Total litter birth weight, kg.	13.0	14.5	14.8	13.9	13.5	1.02
Live pig avg. birth wt., kg.	1.42	1.45	1.46	1.43	1.57	.09
Litter weaning wt., kg.	45.3	53.5	53.4	49.9	48.0	3.97
Pig weaning wt., kg.	6.5	6.5	6.3	6.4	6.2	.18
Gestation wt. change, kg.[c]	+30.3	+32.9	+31.9	+35.0	+31.2	1.40
Lactation wt. change, kg.	-9.1	-10.0	-6.3	-9.8	-7.6	2.31
Lactation feed/sow, kg.	113.2	114.1	119.3	114.7	116.2	3.77

[a]Means are calculated from litters weaning one or more pigs.
[b]Pooled standard error $\sqrt{\frac{\text{Error mean square}}{\text{Observations/treatment}}}$
[c]Gestation weight gain = weight of dam immediately after farrowing minus the weight at breeding.

THE VITAMIN REQUIREMENTS

Recommended dietary levels for each vitamin known to be required by swine are listed in Table 11 for growing/finishing pigs and in Table 12 for breeding swine. The requirements shown here should not be confused with levels of addition. The requirement is the total amount of the vitamin that must be in the diet to support optimal growth with some allowance for "safety." Part or all of this may come from the feedstuffs making up the diet. It the amount provided by the feedstuffs is inadequate then supplementation is required.

Table 11. Vitamin Requirements of Growing-Finishing Swine Fed Ad Libitum (Amount per Kg. Diet)[a]

Liveweight, kg.	1-5	5-10	10-20	20-35	35-60	60-100
Expected daily gain, gm.	200	300	500	600	700	800
Expected efficiency, gm. gain/kg. feed	800	600	500	400	350	270
Vitamin A, IU	2,200	2,200	1,750	1,300	1,300	1,300
or β-carotene, mg.	9	9	7	5	5	5
Vitamin D, IU	220	220	200	200	150	125
Vitamin E, IU	11	11	11	11	11	11
Vitamin K (Menadione, mg.)	2.0	2.0	2.0	2.0	2.0	2.0
Riboflavin, mg.	3.0	3.0	3.0	2.6	2.2	2.2
Niacin, mg.[b]	22	22	18	14	12	10
Pantothenic acid, mg.	13	13	11	11	11	11
Vitamin B-12 (µg).	22	22	15	11	11	11
Choline, mg.[c]	1,100	1,100	900	700	550	400
Thiamin, mg.	1.3	1.3	1.1	1.1	1.1	1.1
Vitamin B-6, mg.	1.5	1.5	1.5	1.1	1.1	1.1
Biotin, mg.	0.10	0.10	0.10	0.10	0.10	0.10
Folic acid, mg.[d]	0.60	0.60	0.60	0.60	0.60	0.60

[a]Requirements reflect the estimated levels of each nutrient needed for optimal performance when a fortified grain-soybean meal diet is fed. Concentrations are based upon amounts per unit of air-dry diet (i.e., 90% dry matter).

[b]It is assumed that most of the niacin present in cereal grains and their by-products is in bound form and thus unavailable to swine. In excess of its requirement for protein synthesis, tryptophan can be converted to niacin (50 mg. tryptophan yields 1 mg. niacin).

[c]In excess of its requirement for protein synthesis, methionine can spare dietary choline (4.3 mg. methionine is equal in methylating capacity to 1 mg. choline).

[d]These levels are suggested. No requirement levels have been established for swine.

SUPPLEMENTATION OF THE CORN-SOY DIET

How does the corn-soy diet stack up against requirements? The present NRC requirements are compared to the vitamins present in a corn-soy diet in Table 13. Note that vitamins A, D, and K, riboflavin, niacin, pantothenic acid, choline, and folacin appear to be deficient. The "Illinois Vitamin Mixture" shown in Table 14 provides for each of these deficiencies and the total amount in the diet then exceeds the NRC requirement for all vitamins except folacin. It is our contention that the NRC requirement for folacin is excessive and the data in Table 9 clearly show that there is no benefit derived from adding folacin to the corn-soy diet. Vitamin E is included in the "Illinois Vitamin Mixture" as a precaution against an undetected selenium deficiency.

Table 12. Vitamin Requirements of Breeding Swine (Amount per Kg. Diet)[a]

	Bred gilts and sows; young and adult boars[b]	Lactating gilts and sows
Vitamin A, IU	4,000	2,000
or β-carotene, mg.	20	10
Vitamin D, IU	200	200
Vitamin E, IU	10	10
Vitamin K (Menadione), mg.	2	2
Riboflavin, mg.	3	3
Niacin, mg.[c]	10	10
Pantothenic acid, mg.	12	12
Vitamin B-12, µg.	15	15
Choline, mg.	1,250	1,250
Thiamin, mg.	1	1
Vitamin B-6, mg.	1	1
Biotin, mg.	0.1	0.1
Folic acid, mg.	0.6	0.6

[a]Requirements for riboflavin and pantothenic acid have been precisely established; other requirements are the estimated levels of each nutrient needed for optimal performance when a fortified grain-soybean meal diet is fed. Concentrations are based upon amounts per unit of air-dry feed (i.e., 90% dry matter). Gestating sows and gilts as well as boars should be fed 1.8 to 2.3 kg per head per day depending upon condition and the environment in which housed.

[b]Requirements for boars of breeding age are lacking. It is suggested that the requirements will not differ significantly from that of bred gilts and sows.

[c]It is assumed that most of the niacin present in cereal grains and their by-products is in bound form and thus unavailable to swine. In excess of its requirement for protein synthesis, tryptophan can be converted to niacin (50 mg tryptophan yields 1 mg niacin).

STRESS AND VITAMIN REQUIREMENTS

Stress is frequently cited as a reason for substantially increasing the levels of vitamins in swine diets. The logic is meaningless without a clear definition of the stress involved. It is true that the riboflavin requirement is increased by cold stress and vitamin K is beneficial when pigs are subjected to moldy corn as a dietary stress. The requirements shown in Tables 11 and 12 allow for enough extra vitamins to sustain the pig in periods of known stress. There is no evidence that the general use of vitamin levels greater than the established requirements is beneficial to the pig.

STABILITY

Vitamin stability relates to the tendency of these organic molecules to undergo chemical changes that lead to a loss in potency. Important factors affecting stability are moisture, temperature, pH, mineral salts present with the vitamin in a mixture, solubility, melting point and particle size of the vitamin, and storage time. Producers mixing on the farm should replenish vitamin premixes frequently rather than purchase large quantities for long-term storage. Moreover, vitamin premixes should be stored under cool, dry conditions. Recommendations by the product supplier should be followed closely to avoid poor pig performance caused by the use of low-potency vitamins.

Table 13. Vitamin Profile of a 16 Percent Crude Protein Corn-Soybean Meal Grower Diet With and Without Vitamin Supplementation (Amount/Kg. Diet)

Vitamin	1979 NRC requirements[a]	Provided by corn and soybean meal	Provided by vitamin mix[b]	Total
Vitamin A, IU	1,300	792.7	3,000	3,792.7
Vitamin D, IU	200	---	300	300
Vitamin E, IU	11	18.0	11	29.0
Vitamin K, mg.	2.0	---	2	2.0
Riboflavin, mg.	2.6	1.3	2	3.3
Niacin, mg.[c]	14	10.19	15	25.2
Pantothenic acid, mg.	11	6.9	10	16.9
Choline, mg.	700	621.4	200	821.4
Vitamin B-12, µg.	11	---	22	22.0
Thiamin, mg.	1.1	3.2	--	3.2
Vitamin B-6, mg.	1.1	3.3	--	3.3
Biotin, µg.	100.	134.6	--	134.6
Folacin, µg.	600.	311.6	--	311.6

[a]NRC. 1979. Nutrient Requirements of Domestic Animals, No. 2. Nutrient Requirements of Swine. Eighth Revised Ed. National Academy of Science-National Research Council, Washington, DC.
[b]See Table 14 for composition and levels of usage.
[c]Estimates of available niacin in corn and soybean meal vary greatly. The values used in this calculation may be considered "conservative".

Table 14. "Illinois Vitamin Mixture" for Fortification of a Corn-Soy Diet

	Per kg. premix	Per kg. diet (0.10% addition)
Vitamin A	3,000,000 IU	3,000 IU
Vitamin D-3	300,000 IU	300 IU
Vitamin E	11,000 IU	11 IU
Vitamin K[a]	2 gm.	2 mg.
Riboflavin	2 gm.	2 mg.
Niacin	15 gm.	15 mg.
d-calcium pantothenate[b]	10 gm.	10 mg.
Choline chloride[c,d]	200 gm.	200 mg.
Vitamin B-12	22 mg.	22 µg.
Carrier	to 1.0 kg.	

Use levels:		
Growing,	5 to 35 kg.	0.10%
	60 to 100 kg.	0.05%
Gestation		0.10%
Lactation		0.10%

[a]From menadione or one of its analogues.
[b]If dl-Ca pantothenate is used, twice the indicated quantity is needed since the l-isomer is not active.
[c]Choline chloride contains 86.8% choline.
[d]For gestation, an additional 300 mg./kg. supplemental choline chloride should be added directly to the diet.

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Estimating Potential Litter Size at Four Weeks After Mating

PHILIP DZIUK

Would it be useful to have an estimate of the potential litter size of your bred gilts and sows during very early gestation? Would you like to know which sows are carrying fewer than six fetuses? If you find it necessary to reduce the number of pregnant sows in your herd, which ones will you keep? Would it be advantageous to save those with nine or more fetuses? If you buy or sell bred gilts would you like some assurance that the animals now are carrying a certain minimum number of fetuses? Would you like to have an absolute test for pregnancy in addition to an estimate of the potential size of the litter at less than 28 days after mating?

Information about all these questions has been generated by recent work in the Department of Animal Science at the University of Illinois. In this research blood from pregnant gilts has been analyzed for hormones produced by the fetus and placenta.

Fetuses produce hormones at very early stages of gestation, perhaps as early as 12 to 14 days after conception. Some of these hormones are produced in sufficient amounts that the hormone, or a form of it, can be detected not only in the fetus but in the mother as well.

Among these hormones are estrone and its metabolite, estrone sulfate. Estrone sulfate can be detected in the blood of a pregnant gilt as early as 18 days after conception. The level rises very sharply until about day 28 of gestation and then falls very precipitously until at day 35, the level is again quite low (Figure 1). From day 20 to day 28, the level in pregnant gilts is always higher than in nonpregnant gilts; hence it is a means of pregnancy diagnosis with 100 percent accuracy.

During this period (day 20 to day 28), the level of estrone sulfate in each gilt is determined by the number of fetuses she is carrying. Each fetus produces a certain amount of estrone sulfate and the total is an accumulative measure of the contribution of each fetus. The greater the number of fetuses, the higher the level of estrone sulfate. We must keep in mind that the level in any one gilt on any one day depends on two factors: the day of gestation, because the level changes with the day; and the number of fetuses. When the day of gestation is known and the level of estrone sulfate is known, then it is possible to estimate the number of fetuses.

To test this principle under experimental conditions we varied the number of fetuses from a low of 1 to a high of 16 by restricting the number of eggs fertilized to produce a low number and by transferring many embryos to achieve a high number. The gilts were then killed at day 35 to count the fetuses. The results are shown in Figure 2. By matching the level of estrone sulfate found in gilts at certain days of gestation with that level in the figure, we could esti-

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mate litter size quite accurately. Gilts with one or more fetuses always had a higher level than nonpregnant gilts, gilts with two or three fetuses had higher levels than gilts with one fetus. It was possible to distinguish correctly between gilts with seven or fewer fetuses and those with eight or more fetuses in 80 percent of cases. We are currently planning to test the system in commercial herds to determine the accuracy under field conditions.

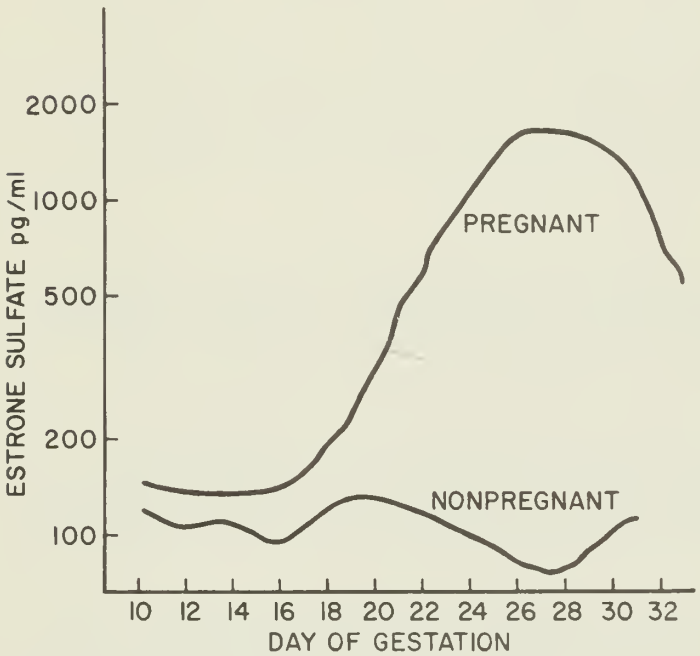

Figure 1. Levels of estrone sulfate in blood of pregnant and nonpregnant gilts.

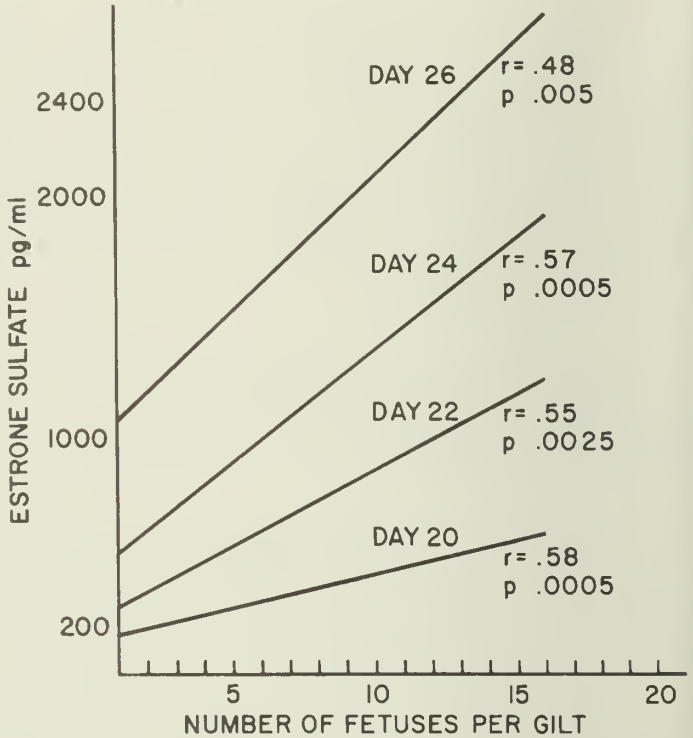

Figure 2. Relationship between level of estrone sulfate in pregnant gilts and number of fetuses.

Plane of Nutrition Prior to Breeding

B.N. DAY

Reproductive performance of the sow herd is generally accepted to be the most important economic trait in swine production. The main production cost is for feed. In turn, considerable attention has been given to the development of management recommendations that will minimize feed costs but at the same time result in a high reproductive rate. The question "How much feed should gilts and sows receive for maximum production efficiency?" is clearly important to the industry but remains difficult to answer conclusively.

Litter size is the single end measurement of a number of complex biological systems that are primarily controlled by the environment of the sow. In most swine herds, reproductive efficiency could be improved by the development of improved management systems that would effectively reduce average age at puberty, prevent the occurrence of delayed puberty, improve conception rate, increase ovulation rate in gilts, reduce the high level of embryonic mortality during the first month after breeding, minimize stillbirths, and decrease the interval from farrowing to the subsequent pregnancy.

Considerable attention has been given to the effects of environmental factors, including nutritional requirements, on the above components of the reproductive cycle, and progress has been made. For example, the beneficial economic effects of reduced feed intake during pregnancy is widely recognized and the practice of restricted feeding has been adopted by swine producers. Also there is close agreement among research studies that energy intake prior to breeding is related to ovulation rate in gilts.

On the other hand, management recommendations are not so clearly established on the optimum environmental conditions, including feeding level, required for early puberty, high conception rates, and a short interval to post-weaning estrus. A major reason for this uncertainty has been failure of specific feeding regimens to be effective under variable management systems. These differences have undoubtedly been due, in many cases, to unknown experimental or physiological factors. A further complicating factor has been the design of experiments in this area of study. Most traits used to measure reproductive performance such as litter size are extremely variable. At the same time, the number of animals available for study is often limited as compared to related studies on growth and carcass quality. As a result, experimental differences considered to be improvements in reproductive performance have frequently not been observed in repeated studies, and small but economically important changes in reproductive performance have gone undetected due to an insufficient number of experimental animals. For example, studies involving 10 or fewer sows per experimental group have frequently been used to measure environmental effects on litter size at birth when 30 sows per group are needed to detect ($P<.05$) a 20 percent difference (about 2 pigs) in litter size in 80 percent of the tests (Hays *et al.*, 1969).

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The purpose of this discussion will be to review previous studies concerning the effects that feeding level prior to breeding has on estrus and ovulation rate in gilts and sows. Particular emphasis will be placed on energy intake.

AGE AT PUBERTY

In commercial swine production, the level of feed intake during the growing-finishing and gilt development periods does not appear to have a major effect on age at puberty. Age is a much more reliable predictor of time of puberty than is body weight. When gilts were placed on restricted energy intake (60 to 70 percent of *ad libitum*) at approximately 2 to 3 months of age, age of puberty was not consistently influenced even though body weight at the time of sexual maturity was decreased. Anderson and Melampy (1972) reported, in a review that restricting the level of energy intake *delayed* puberty an average of 16 days in 9 experiments but *hastened* the age at puberty by 11 days in 5 separate studies.

Severe long-term restrictions in energy intake that fail to provide acceptable growth rate or that cause nutritional disorders may be expected to delay puberty. Burger (1952) found that puberty was delayed 46 days by restricting feeding level to 50 percent of that provided full-fed controls. However, the different management practices of either moderate limitations in energy intake during a gilt development period or *ad libitum* feeding to the first estrus, would not appear to be a major cause of variations observed among herds in age at puberty. Breed, seasonal changes, housing management, social environment, and degree of inbreeding have been shown to be important factors contributing to the problem of delayed puberty in gilts.

OVULATION RATE IN GILTS

Although age at puberty is not influenced markedly by restricted energy intake during the prepubertal period, feeding level during the 2 to 3 week period prior to mating has a major effect on ovulation rate in gilts. "Flushing" is an accepted practice among swine producers and numerous trials have shown that increasing the feeding level of gilts on a restricted diet will increase ovulation rate. Both the amount of feed fed during the flushing period and the degree of energy restriction before flushing are important factors in determining the amount of increase in ovulation rate due to the high energy diet. In general restricted gilts provided *ad libitum* feeding prior to breeding ovulate 1 to 2 more ova than gilts continuously restricted to two-thirds the *ad libitum* level. Zimmerman *et al.* (1960) have shown that the optimum duration of flushing is about 10 to 14 days and that the addition of fats or sugars to the diet to increase energy intake will provide the flushing effect. The practical advantage of the increase in ovulation rate due to flushing would be improved litter size. Although the data available on the effect of flushing on litter size are limited, a favorable response has generally been observed in the average number of embryos present at 25 to 40 days of gestation and at term.

The physiological mechanisms involved in the change in ovulation rate due to short-term increases in energy intake are not established.

Flushing during estrus. Studies have been conducted on the effect of reducing the length of the flushing period to a single day during estrus. In an initial study, when feed intake was increased from 1.4 to 4.1 kg/gilt at a single feeding on the day of mating, average ovulation rate was increased by 2.6 corpora lutea (Lodge and Hardy, 1968). The results of repeated studies have been inconsistent.

For example, Naber and Zimmerman (1971) found no increase in ovulation rate when daily feed intake of restricted gilts (1.36 kg feed/day) was increased to 4.1 kg as a single feeding on the first day of estrus whereas a comparison group of gilts flushed by the conventional method (2.27 kg feed/day for 14 to 21 days prior to estrus) had an average of 1.7 more corpora lutea than the restricted gilts.

Protein level. Few studies have been made of the effects of protein level on ovulation rate. Robertson *et al.* (1951) found that gilts fed a diet containing 15 to 20 percent protein tended to have a higher ovulation rate than gilts receiving a reduced protein diet (11 to 15 percent) if on pasture, but the difference was reversed under drylot conditions. More recently Jones and Maxwell (1974) observed a significant increase in the average number of corpora lutea at 30 days of pregnancy with higher levels of protein intake prior to ovulation. Gilts receiving diets containing 8, 14 and 20 percent protein had an average of 12.9, 13.8, and 14.7 corpora lutea, respectively. The daily intake of protein on the three diets was 143, 254, and 345 grams.

Other nutrients. There appears to be little evidence that either vitamin or mineral deficiencies have a direct detrimental effect on ovulation rate.

POST-WEANING ESTRUS AND OVULATION IN SOWS

How should sows be fed and managed from weaning to rebreeding to obtain maximum reproductive performance? This question is frequently asked and producers have strong opinions that represent totally different approaches to the problem. Some producers feel that removal of feed and/or water for 1 to 2 days after weaning will reduce the interval to post-weaning estrus, result in a higher percentage of sows exhibiting a post-weaning estrus, and improve synchronization of estrus. Reasons given for improved performance following feed and/or water restriction are that it helps to dry up the sow and also that the restriction may be a form of stress conducive to the stimulation of ovarian activity and estrus. Other producers believe that the most effective management practice in stimulating synchronized post-weaning estrus in a high percentage of sows is to feed at a moderate to high level following weaning and to minimize exposure of the sows to stress. Individual examples of improved performance have apparently been observed with both management systems. Whether or not uncontrolled factors may have led to a misinterpretation of the actual cause of the change in performance is of course not known. Not enough controlled comparisons under different environmental conditions exist to resolve the question completely. However, the available data indicate that fasting sows after removal of pigs does not have a beneficial effect on the occurrence of estrus and may cause a decrease in ovulation rate.

In a study conducted in New Zealand by Shearer and Adam (1973), starvation for 24 hours after weaning increased the average interval from weaning to estrus from 8.5 to 13.1 days and resulted in an average decrease of 2.8 pigs in subsequent litter size. Control sows were fed 2.7 kg of feed daily as were the experimental sows following the starvation period. Tribble and Orr (1977) found no beneficial effect of fasting sows for 2 days after weaning as compared to feeding 4 lb. per head per day from weaning to estrus (Table 1).

Table 1. Effect on Feeding Level of Sows Following Weaning on Reproductive Performance

(From Tribble and Orr, 1977)

Item	Feeding level, lb. 4	0-6[a]
No. of sows	98	98
No. of sows bred	94	87
Days weaning to breeding	4.4	4.4
Avg. pigs farrowed/litter	10.5	10.4

[a]No feed for 2 days followed by 6 lb. per head per day until bred.

In a recent study conducted at North Dakota State University by Allrich *et al.* (1979), sows were fasted for 0, 2, 3 or 4 days following removal of pigs at 21 or 30 days of age. Water was provided. Within a lactation group, fasting did not alter the interval from weaning to first estrus. The effects of fasting on ovulation rate was variable although sows fasted for 4 days had significantly fewer corpora lutea. Number of normal embryos was not affected by fasting. Fasting for 2 days after a 30-day lactation significantly decreased litter size at term.

In a preliminary experiment involving a limited number of sows, no beneficial effects on the occurrence of post-weaning estrus in sows were observed due to feed or feed and water restriction for a 48-hour period (Table 2).

Table 2. Effect of Management on Interval to Post-Weaning Estrus in Confinement Sows

Treatment group[a]	No. of sows	Days to estrus Mean[b]	Standard deviation	Range
Control	18	5.9	1.4	4-9
Feed restriction	19	8.2	4.0	4-16
Feed and water restriction	17	7.4	4.4	3-21

[a]Feed or feed and water were withheld for 48 hours after weaning.

[b]Differences among treatment means were not statistically significant.

Flushing. The interval available for flushing sows is restricted to a period of about 4 to 8 days and may be insufficient to obtain the maximum effect of high energy intake on ovulation rate, particularly in those sows first returning to estrus after weaning. Trends have been observed, however, toward increased litter size in sows as the level of feed intake was raised between weaning and mating (Brooks and Cole, 1972). Increased feed intake only during the post-weaning estrus does not appear to affect litter size (Brooks and Cooper, 1971). Zimmerman (1966) reported that ovulation rate of sows was not significantly improved by flushing following 30 days more of restricted feeding after weaning.

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Roles of Maternal Nutrition and Ovarian Function in Porcine Fetal Development

L.L. ANDERSON

Reproductive potential in pigs is an important factor contributing to their total meat production. A high rate of productivity is dependent upon early sexual maturity, a comparatively high ovulation rate, relatively brief periods of gestation and lactation, and the capability of repeating the preganancy cycle soon after weaning a litter. Important limitations affecting this production potential are ovulation rate, embryonic death, and perinatal and neonatal losses.

During gestation sows lose about *half* of the potential litter size because of embryonic and fetal deaths. Although gilts and sows may ovulate 15 to 20 eggs during the heat period and more than 95 percent of those ova are fertilized by spermatozoa, approximately 7 to 10 of the developing embryos perish at some stage during the pregnancy. Thus, litter size at parturition is reduced to approximately 8 to 11 or 12 living piglets. A series of experimental investigations in our laboratory has been designed to determine factors affecting embryonic and fetal survival in the pig, particularly the roles of the maternal endocrine system and maternal nutrition on fetal development during different stages of gestation. The investigations have been extended to examine the effects of nutritional and hormonal treatments of gilts during middle or late gestation on subsequent litter size and growth of the neonates.

A brief review of normal reproductive characteristics of gilts and sows during the estrous cycle and pregnancy is followed by a discussion of experimental evidence on the effects of maternal nutrition and ovarian hormones on fetal survival.

NORMAL REPRODUCTIVE CHARACTERISTICS

Estrous Cycle. The estrous cycle may be categorized into a brief follicular phase (proestrus and estrus or heat) and a long luteal phase. During the proestrous and estrous phases, maturing ovarian follicles produce estrogenic hormones that induce the sexual behavior patterns typical of a sow approaching heat. The mature follicles ovulate several hours after onset of standing heat. After ovulation, the cells lining the now collapsed follicle wall proliferate into a solid mass of tissue, the corpus luteum.

The luteal phase of a normal 21-day cycle is characterized by rapid growth of the corpus luteum and secretion of progesterone from it to *day 16*, and then rapid regression to a nonsecreting tissue (corpus albicans). The progesterone produced by the corpus luteum sustains the behaviorally quiescent phase of the cycle, inhibits uterine motility, and maintains secretory activity of endometrial cells within the uterus. Thus, the corpora lutea play a predominant role in regulating the interestrous interval by their production of progesterone. When the corpora fail, progesterone levels decline and newly developing follicles produce estrogens to again initiate an estrous phase of the cycle.

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Pregnancy. After mating, the ovulated eggs are fertilized within a few hours by spermatozoa migrating through the uterus to anterior regions of the oviducts. The embryos enter the uterus approximately 90 hours after fertilization. At *days 4* to *12* of pregnancy, embryos migrate within the uterine lumen, rapidly develop into blastocysts which then form extremely elongated (e.g., >60 cm) filamentous membranes (Anderson, 1978). Intrauterine spacing of embryos is an end-to-end arrangement that is essentially complete by *day 13*, and results in an even distribution of the embryos throughout both uterine horns. Implantation or attachment of the conceptuses to the uterine wall occurs between *days 14* and *18*, and the conceptuses (embryos with their placental membranes and fluids) develop rapidly. Thus, the first 30 days after breeding represent a period of fertilization, embryo migration and spacing, implantation, and placentation, and a time when the greatest proportion of embryonic losses occurs. The conceptuses continue to grow but uterine space for them does not become restrictive to fetal survival until late pregnancy. Fetoplacental growth increases to approximately 16 kg at term, or about 10 percent of the body weight of the dam.

Pregnancy lasts about 115 days. Unlike corpora lutea in cyclic sows, those corpora that develop soon after mating continue hormone secretion to near term. Within a few hours before parturition the corpora lutea lose their vascularity, regress rapidly, and continue to decline during the lactational phase. Corpora lutea are essential for maintenance of pregnancy to term in the pig. Progesterone concentrations in peripheral blood increase to peak values by *day 12* and gradually decrease to levels of 20 to 25 ng/ml by *day 104* (Fig. 1). Near the onset of parturition, progesterone concentrations steadily decline, and they reach basal levels of 1 to 2 ng/ml during lactation.

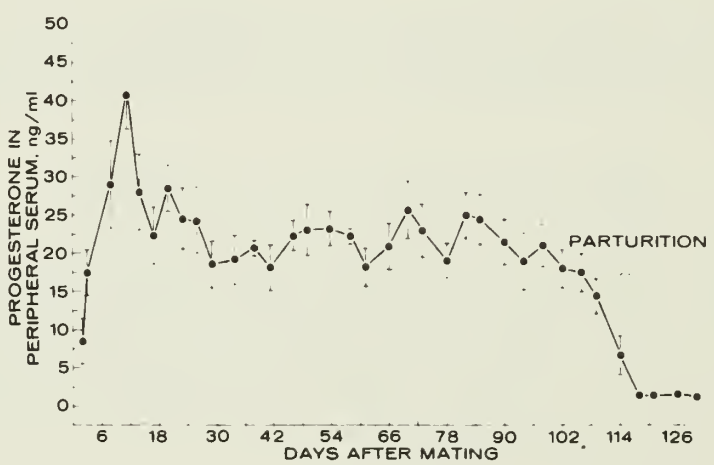

Figure 1. Profile of progesterone concentrations in peripheral blood serum throughout normal pregnancy and in early lactation in the pig. Carpenter and Anderson, 1979; Hard and Anderson, 1979a.

Relaxin is produced and accumulated in corpora lutea of sows throughout pregnancy and then is released into ovarian venous and peripheral blood just before parturition (Belt *et al.*, 1971; Anderson *et al.*, 1973; Sherwood *et al.*, 1975). Relaxin stimulates cervical softening and dilatation, and also reduces the duration of parturition (Kertiles and Anderson, 1979). Thus, during pregnancy the corpora lutea not only secrete progesterone, which is essential for the maintenance of pregnancy in this species, but also accumulate and secrete relaxin. The production and secretion of these markedly different hormones (a steroid and a protein) by the same luteal cell do not coincide. Progesterone is secreted by the lutein cells within the corpora lutea throughout pregnancy, whereas relaxin

is released only during the last days of gestation. The pituitary gland hormones are required to maintain corpora lutea for progesterone secretion during pregnancy in this species (Anderson *et al.*, 1965; 1967; duMesnil duBuisson *et al.*, 1964; duMesnil duBuisson and Denamur, 1969; Kraeling and Davis, 1974); however, an understanding of the endogenous endocrine control of the secretion of relaxin will require further investigation.

Ovulation Rate. Ovulation rate is associated with breed, amount of inbreeding, age at breeding, and weight at breeding (reviewed by Anderson and Melampy, 1972). Reproductive experience also correlates with ovulation rate; ovulations increase with the number of births to seven or more litters. Inbreeding reduces ovulation rate whereas crossing inbred lines increases markedly the number of ovulations.

High-energy diets induce a high ovulation rate when the diets are fed for a restricted period. The number of ovulations is predominantly affected by gentic background; nevertheless, ovulation rate is usually affected positively with increasing levels of energy intake.

Conception Rate. Fertilization rate in pigs in usually high (e.g., >90 percent). Ovulation rates have little or nor effect on fertilization rate.

Embryonic and Fetal Survival Rates. Embryonic deaths may result from genetic defects with the gametes (ova and spermatozoa); improper timing for fertilization of gametes caused by premature or delayed breeding of the sow; or accelerated or delayed transport of the embryos from the oviducts into the uterine horns. Embryonic deaths resulting from inherited genetic defects of gametes usually occur within the first 2 weeks after breeding and are beneficial in eliminating potentially weak or deformed offspring (Bomsel-Helmreich, 1961; Bishop, 1964). A variety of abnormalities of the male and female reproductive systems can result from genetic defects (Bishop, 1972).

At least 40 percent or more of the embryos are lost before parturition, and a major part of this loss occurs during the first half of pregnancy (Casida, 1953; Hanly, 1961; Lasley, 1957; Anderson, 1978). Uterine capacity does not become a major factor limiting litter size during the first third of gestation, but placental insufficiency is a cause of increased fetal death and decreased fetal growth during the last two-thirds of pregnancy (Pope *et al.*, 1972; Knight *et al.*, 1977).

Maternal Nutrition and Litter Size. Although litter size increases by about two piglets between the first and third gestation, this is unrelated to nutritional status of the dam. Restricting metabolizable energy intake (e.g., <5,000 kcal/day) throughout gestation has no detrimental effect on fetal survival rate, and only a slight decrease occurs in birth weight. Numerous experiments have indicated that high energy diets (e.g., >7,500 kcal/day) given throughout gestation reduces litter size whereas piglet birth weight increases (Wrathall, 1971; Anderson and Melampy, 1972; Pond, 1973). The high energy intake stimulates ovulation rate but it also increases fetal mortality; thus, fetal survival rates remain equivalent to those in dams fed normal levels of caloric intake.

Fetal survival rates remain unaltered by marked shifts in caloric or protein intake of the dam at all stages of gestation in this species. Severe protein restriction of the dam, however, reduces not only birth weight but also postnatal development (Pond *et al.*, 1969; McCance and Widdowson, 1974). Although there is considerable information concerning quantitative protein and energy

requirements for pregnant gilts and sows, little is known about the long-term effects of prenatal malnutrition on the development of the progeny.

EXPERIMENTS ON THE ROLES OF MATERNAL NUTRITION AND OVARIAN HORMONES IN EMBRYONIC AND FETAL DEVELOPMENT

These experiments on conceptus development are divided into early, middle, and late pregnancy, and postnatal growth and reproductive performance of offspring from the experimental dams.

Embryonic Development During First Third of Pregnancy. Experiments were designed to determine whether gilts can provide an adequate uterine environment for the survival and growth of embryos when the food intake of the dam is limited, and whether supplemental ovarian steroids ensure continued embryonic and placental development under these conditions (Anderson, 1975). Yorkshire gilts were given water only (0 kcal/day, inanition) beginning 10 days before mating and continuing for varying peroids after mating (Fig. 2). The uterus and conceptuses were recovered by hysterectomy in the experimental animals and full-diet (7,028 kcal/day) controls. In one group of gilts subjected to inanition, the ovaries were surgically removed on *day 22* and these animals were given daily injections of progesterone (0.8 mg/kg body weight) and estradiol benzoate (5 µg/kg body weight) daily from *days 22* to *34* of this period of inanition. In unmated pigs subjected to inanition, estrous cycles ceased and ovarian follicles were completely regressed by *day 34*.

Table 1. Effect of Inanition on Embryonic Survival in the Pig

Days after mating	Days of inanition	No. of pigs		No. of embryos*	
		Mated	Remaining pregnant	Living	Degenerating
			Control		
14	0	6	6	8.7 ± 1.0	1.0 ± 0.5
18	0	6	6	11.1 ± 1.0	0.2 ± 0.5
22	0	6	6	11.0 ± 1.0	0.5 ± 0.3
26	0	6	6	9.8 ± 1.0	0.0
30	0	6	6	10.8 ± 1.0	0.3 ± 0.2
34	0	6	6	10.5 ± 1.0	0.0
			Inanition		
14	25	6	6	6.5 ± 1.0	1.3 ± 0.5
18	29	6	5	8.6 ± 1.1	0.2 ± 0.1
22	33	6	4	9.3 ± 1.2	0.0
26	37	6	4	9.0 ± 1.2	1.0 ± 0.6
30	41	6	2	10.0 ± 1.7	0.5 ± 0.3
34	45	6	1	10.0	1.0
			Inanition plus progesterone and estradiol benzoate		
34	45	6	6	9.0 ± 1.0	0.0

*Values are means ± SE.
Anderson, 1975.

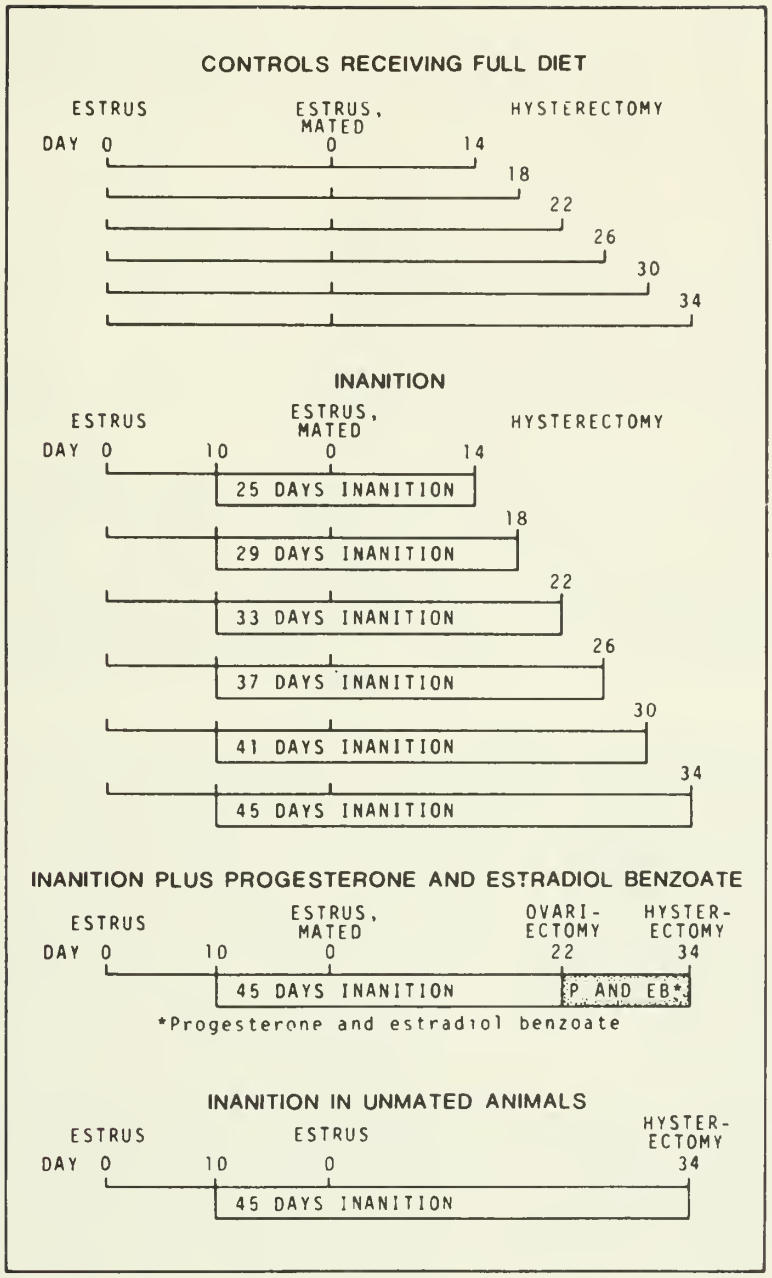

Figure 2. Description of control and experimental groups indicating days of estrus, mating, and treatment periods. Body weight only was determined at regular intervals in a group of unmated pigs on full diet; this group is not illustrated in figure. Anderson, 1975.

All mated pigs in the control groups receiving a full diet remained pregnant (6/6) at each stage (*days 14, 18, 22, 26, 30,* and *34*) of pregnancy (Table 1). Pregnancies were maintained in 79 percent of the gilts (19 of 24 dams) up to *day 26*, but only a few animals (3 of 12, or 25 percent) remained pregnant when food deprivation extended to *days 30* and *34* pregnancy. When the restricted gilts were given daily injections of optimal levels of progesterone and estradiol benzoate, all of them (6 of 6), remained pregnant to *day 34*. Furthermore, in gilts remaining pregnant during inanition the average number of living embryos remained similar to that found in the full-diet controls at each stage of pregnancy examined. The number of degenerating embryos also remained similar in experimental and control gilts.

Embryonic and placental development were determined on the basis of nitrogen content (Fig. 3). The nitrogen content of the embryo increased exponentially between *days 14* and *34* in gilts on a full diet and in those subjected to inanition.

By *day 30*, nitrogen content was less ($P<0.05$) in embryos from nutritionally deprived gilts than in embryos from the control animals; this difference increased ($P<0.01$) by *day 34*. During prolonged inanition, exogenous progesterone and estrogen from *days 22* to *34* increased ($P<0.01$) nitrogen content in embryos; this increase was similar ($P>0.05$) to that found in control dams.

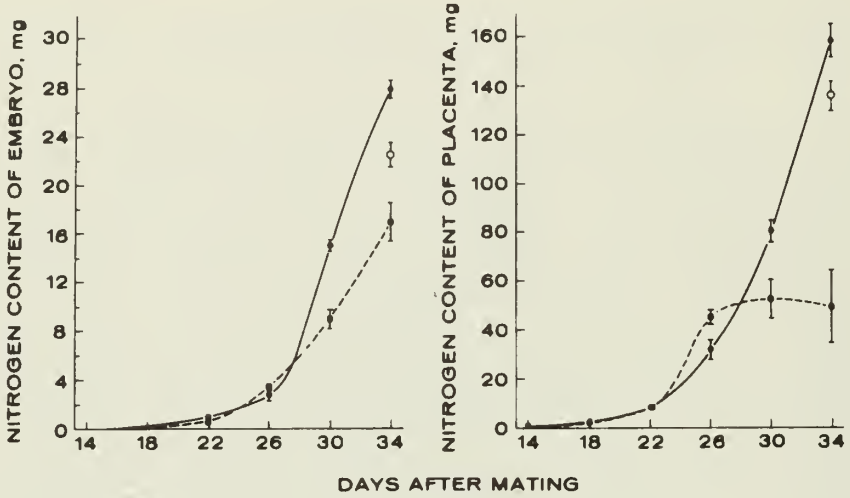

Figure 3. Nitrogen content of embryos and placental membranes in pigs given a full diet (●), in animals subjected to inanition 25-45 days (■), and in pigs given exogenous progesterone and estradiol benzoate during 45 days inanition (O). Number of conceptuses in pigs given a full diet was 52, 67, 66, 59, 65, and 63 at days 14, 18, 22, 26, 30, and 34, respectively; in animals subjected to inanition, number of conceptuses was 39, 43, 37, 36, 20 and 10 at days 14, 18, 22, 26, 30, and 34, respectively; and in those given exogenous progesterone and estradiol benzoate, number of conceptuses was 54 at day 34. Values are means ± SE. Anderson, 1975.

Nitrogen content of the placenta increased in a similar pattern ($P>0.05$) between *days 14* and *30* in animals on a full diet and in those on inanition (Fig. 3). Continuation of inanition to *day 34* resulted in a severe limitation ($P<0.01$) in placental nitrogen deposition as compared with that in controls. Exogenous progesterone and estrogen given between *days 22* and *34* resulted in placental nitrogen content similar ($P>0.05$) to that found in gilts on a full diet.

These results indicate that with adequate progesterone and estrogen, maternal components are made available for development of the conceptuses in spite of nutrient deprivation of dams during early pregnancy. When corpora lutea fail under these adverse conditions for the dam, the pregnancy is lost quickly. Furthermore, an adequate uterine environment permitting transfer of maternal nutrients across the placentas to the embryos for their continued normal development can be maintained by experimental treatment with progesterone and estrogen in nutritionally deprived gilts during early stages of embryonic development.

Dietary Restriction and Ovarian Hormones During Middle Third and Last Third of Pregnancy. Fetal and placental growth represent approximately 5 percent of the dam's body weight by *day 70* and 10 percent by *day 110*. Dietary restriction of the dam during late stages of gestation may have a more detrimental effect on development of the conceptuses than found during early pregnancy.

Experiments were designed to determine the effects that a low level of caloric intake during the middle third and last two-thirds of pregnancy would have

on fetal survival rates, fetal growth, and placental development, as well as the effects of exogenous progesterone (P) and estradiol benzoate (EB) on survival and development of conceptuses (Anderson and Dunseth, 1978).

Yorkshire gilts were subjected to nutrient deprivation (2,208 kcal/day; 0.80 kg ration/day) or given a control diet (5,008 kcal; 1.82 kg ration/day) for either 40 days during the middle third *(days 30* to *70)* or 80 days during the middle and last third *(days 30* to *110)* of pregnancy. Half the gilts in either group were ovariectomized (ov) at *day 30* and then given daily injections of progesterone and estradiol benzoate. Fetal survival rate in both experimental and laparotomized (Lp) control animals was 58 percent (Table 2). Exogenous progesterone and estrogen sustained pregnancy after ovariectomy but did not increase fetal survival rate or fetal growth regardless of level of feeding to *day 70* or *110*.

Effect of Nutrient Deprivation During Middle Third and Last Third of Pregnancy on Fetal Survival. Yorkshire gilts were subjected to caloric restriction (0 kcal/day; water only) during either the middle third or last third of pregnancy, and fetoplacental development was compared with that in full-fed controls (7,028 kcal/day; 2.72 kg ration/day; Anderson *et al.*, 1979). A description of the experimental and control groups is in Fig. 4.

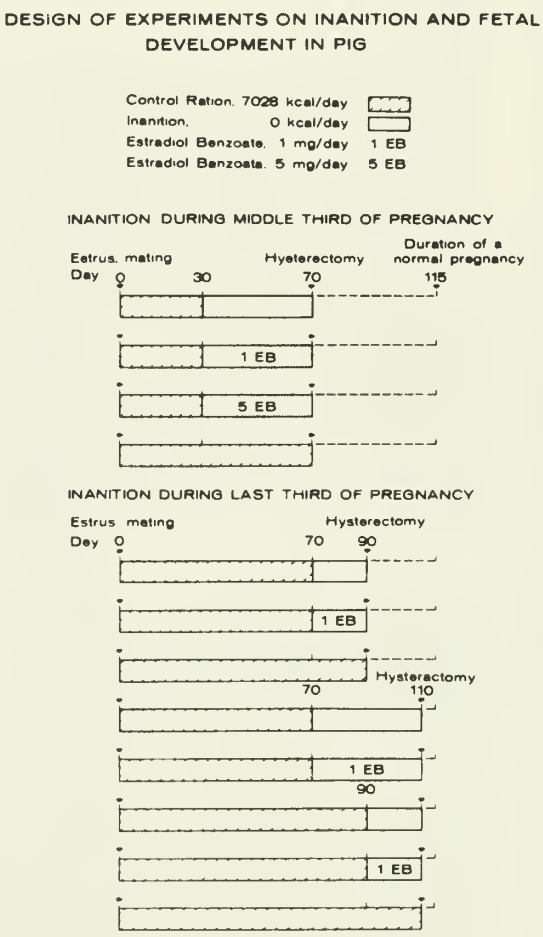

Figure 4. Description of control and experimental groups, indicating duration of a normal pregnancy, days of estrus, mating, and hysterectomy, and duration of full diet, inanition, and estrogen treatment during pregnancy in the pig. Anderson et al., 1979.

Pregnancies were maintained in 81 percent of the gilts subjected to inanition during either the middle third or last third of gestation as compared with 100 percent in full-fed controls (Table 3). The average number of living fetuses in nutritionally deprived gilts was similar to that in full-fed controls. Fetal survival rates also were similar in experimental and control animals.

Fetal weight increased fourfold between *days 70* and *110* (Table 3). Fetal growth was limited ($P<0.05$) by prolonged inanition to *day 70* compared with the

Table 2. Fetal Survival and Growth During Dietary Restriction in Pig

	Days after mating	Ration, kg/day*	No. of pigs mated/pregnant	No. of fetuses		Fetal survival rate, pct.	Wt. of living fetuses, gm
				Living	Degenerating		
Lp control	70	1.82	6/5†	10 ± 1.1	1 ± 0.5	73	238 ± 6
Lp control	70	0.80	7/7	10 ± 1.6	1 ± 0.6	62	200 ± 5
Ov + P & EB	70	1.82	6/6	9 ± 1.5	1 ± 0.6	57	227 ± 6
Ov + P & EB	70	0.80	7/7	8 ± 1.4	3 ± 1.0	47	217 ± 5
Lp control	110	1.82	6/6	10 ± 1.1	2 ± 0.9	62	959 ± 30
Lp control	110	0.80	7/5‡	7 ± 1.4	3 ± 2.6	45	915 ± 37
Ov + P & EB	110	1.82	6/5§	10 ± 0.9	<1 ± 0.2	67	794 ± 22
Ov + P & EB	110	0.80	6/6	8 ± 1.2	1 ± 0.7	54	673 ± 21

Values are means ± SE. *Kilograms of ration per day after *day 30*. †Uterus of one pig contained 0 living and 11 degenerating fetuses at *day 70*. ‡Pregnancy lost after *day 30* in one animal and one pig aborted at *day 74*. §Uterus of one pig contained 0 living and 12 degenerating fetuses at *day 110*.

Anderson and Dunseth, 1978.

Table 3. Fetal Survival During Prolonged Inanition in the Pig

	Days after mating	Inanition		No. of pigs			No. of living fetuses	Fetal survival rate, pct.	Weight of living fetuses, gm
		Days of pregnancy	No. of days	Mated	Remaining pregnant	pct.			
Inanition	70	30-70	40	4	3	75	9.3 ± 1.67	64 ± 16	215 ± 4.6
Inanition, 1 mg EB	70	30-70	40	4	3	75	11.7 ± 0.33	70 ± 9	211 ± 5.4
Inanition, 5 mg EB	70	30-70	40	4	3	75	7.3 ± 1.45	47 ± 17	177 ± 11.4
Control, full diet	70		0	7	7	100	10.9 ± 1.01	72 ± 6	234 ± 4.7
Inanition	90	70-90	20	4	4	100	11.3 ± 1.11	79 ± 7	542 ± 19.8
Inanition, 1 mg EB	90	70-90	20	4	3	75	12.7 ± 0.67	68 ± 8	516 ± 14.5
Control, full diet	90		0	4	4	100	9.0 ± 0.71	59 ± 6	526 ± 20.0
Inanition	110	70-110	40	4	2	50	10.0 ± 0.00	83 ± 0	913 ± 31.1
Inanition, 1 mg EB	110	70-110	40	4	3	75	8.0 ± 2.65	46 ± 12	717 ± 31.1
Inanition	110	90-110	20	4	4	100	11.0 ± 1.08	68 ± 8	998 ± 20.8
Inanition, 1 mg EB	110	90-110	20	4	4	100	8.3 ± 1.31	58 ± 7	879 ± 37.0
Control, full diet	110		0	8	8	100	8.9 ± 1.11	58 ± 7	984 ± 26.7

Values are means ± SE.

Anderson *et al.*, 1979.

growth in full-diet controls. In starved dams given estradiol benzoate, fetal development was further reduced ($P<0.01$) in comparison with controls. At *day 110*, fetal growth in dams subjected to inanition was similar ($P>0.05$) to that found in controls; in those starved gilts given EB, however, the fetuses were limited severely ($P<0.01$). Placental insufficiency was the primary cause of reduced fetal growth and resulted in abortion in only a few of the dams.

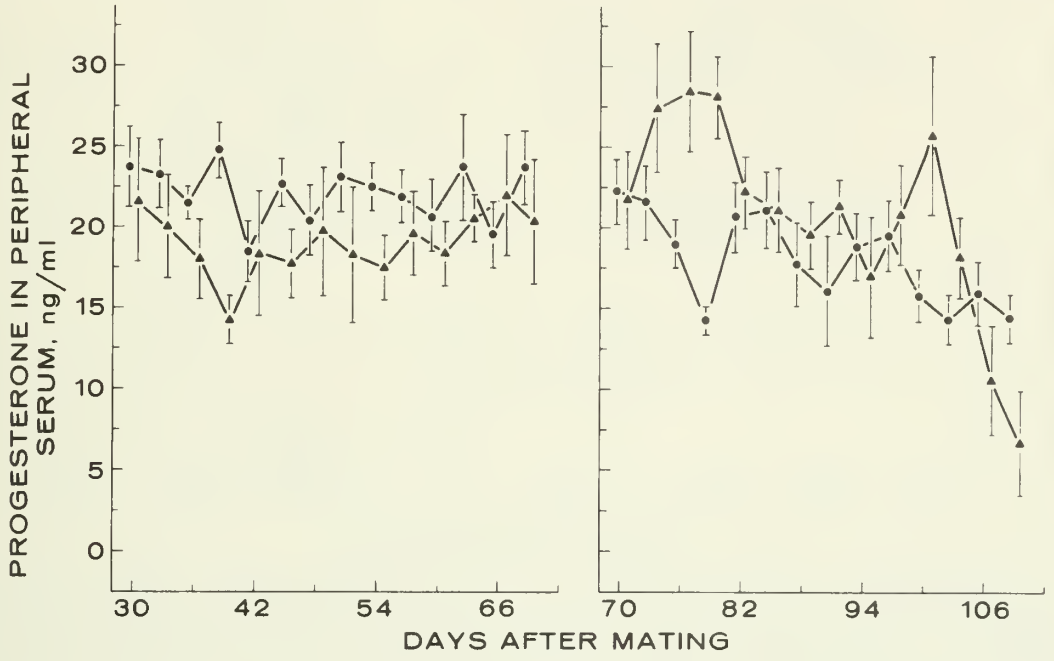

Figure 5. Progesterone concentrations in peripheral blood serum in Yorkshire pigs subjected to 40 days of starvation (▲) during either middle third (days 30-70) or last third (days 70-110) of pregnancy compared with those in full-diet controls (●) during these 2 stages of pregnancy. Values are means ± SE from sequential blood samples of starved and control pigs. Progesterone levels were determined in 7 pigs starved days 30-70 and in 8 animals starved days 70-110 and compared with those in 11 full-diet controls from days 30 to 70 and 11 full-diet controls from days 70 to 110. Pregnancy was maintained in all starved and control pigs. Anderson et al., 1979.

Progesterone concentrations in peripheral blood serum of the gilts subjected to inanition during either the middle third or last third of pregnancy were maintained at levels (18 to 25 ng/ml) similar ($P>0.05$) to those found in full-fed controls (Fig. 5). A precipitous decline in serum progesterone concentrations in these starved gilts was found only during late pregnancy, between *days 100* and *110*, but pregnancies were maintained in these animals. Progesterone levels in peripheral serum of dams in which pregnancy failed during 40 days of starvation in either the middle third or last third of gestation are compared with those in pregnant full-diet controls (Fig. 6). During starvation in one dam from *days 30* to *57*, serum progesterone levels remained equivalent to or above those found in full-diet controls, but steroid concentrations dropped precipitously 3 days before abortion on *day 63*. In two dams starved during the last third of gestation, serum progesterone levels remained near those found in the controls from *days 70* to *88*, but steroid concentrations declined sharply in these starved dams 3 days before abortion on *days 97* and *100*. Abortion occurred in the nutritionally deprived gilts only when serum progesterone concentrations dropped to <10 ng/ml within 3 days before loss of the conceptuses. Cholesterol levels in peripheral serum remained stable during starvation and increased only during the last days late in

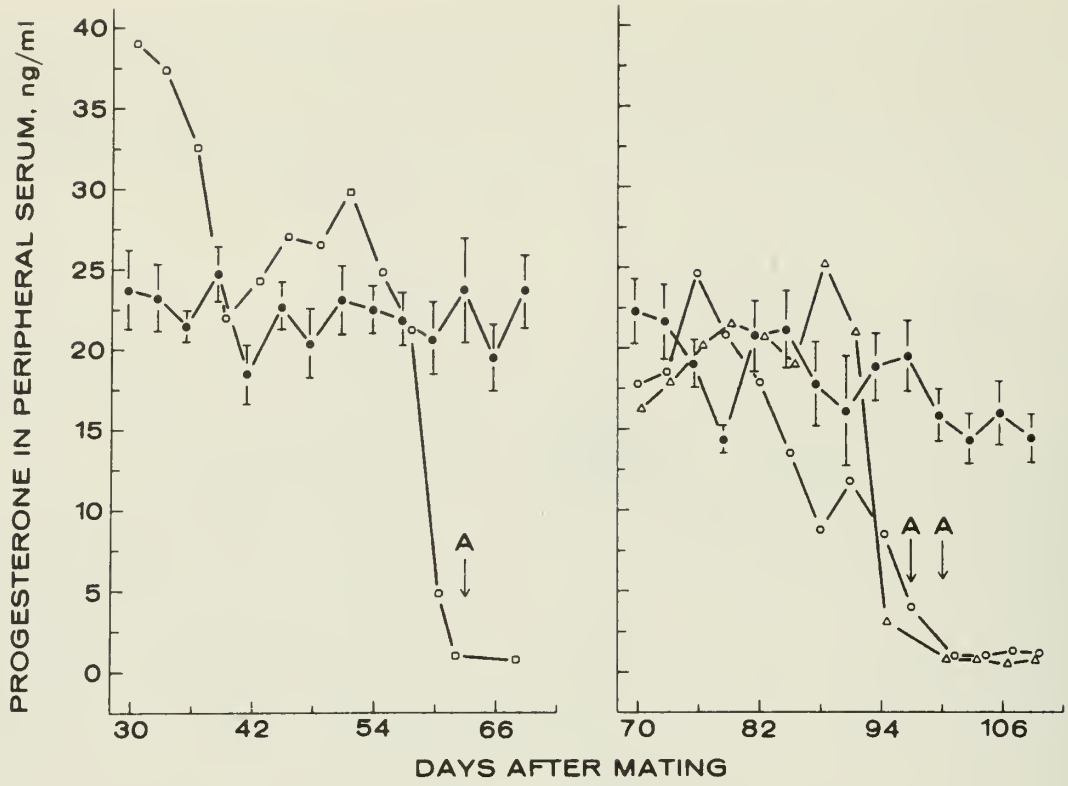

Figure 6. Progesterone concentrations in peripheral blood serum from Yorkshire pigs in which pregnancy failed during 40 days of starvation during either middle third (days 30-70) or last third (days 70-110) of pregnancy compared with those in full-diet controls, which remained pregnant during these 2 stages of gestation. Arrows with superscript A indicate when abortion occurred in relation to progesterone secretion in 3 starved pigs during middle third (□) and last third (△,○) of pregnancy. Values are means ± SE for full-diet controls. Anderson et al., 1979.

gestation. Concentrations of maternal serum proteins, urea nitrogen, sodium, potassium, calcium, and iron also were sustained at adequate levels to maintain normal development of porcine conceptuses during prolonged starvation in middle or late pregnancy (Kertiles *et al.*, 1979). Serum levels of glucose during dietary restriction also were similar to those in full-diet controls (Anderson and Dunseth, 1978).

Effect of Nutrient Deprivation During Middle or Late Pregnancy on Litter Size and Neonatal Growth. In a subsequent series of experiments, Yorkshire gilts were subjected to caloric restriction either during the middle third *(days 30* to *70)* or last third *(days 50-90)* of pregnancy and then gradually realimentated to a full diet and allowed to advance to parturition (Hard and Anderson, 1979a). The full-diet controls received 7,028 kcal/day throughout gestation and those animals subjected to inanition (0 kcal/day) received water only. A description of experimental and control groups of gilts is presented in Fig. 7.

Pregnancies were maintained in 83 percent of the gilts calorically restricted in the middle third of pregnancy and in 64 percent of those dams restricted in the last third as compared with 100 percent in the controls (Table 4). At parturition, average litter size of living piglets in starved dams (9.4) was similar ($P>0.05$) to that found in full-fed controls (8.0).

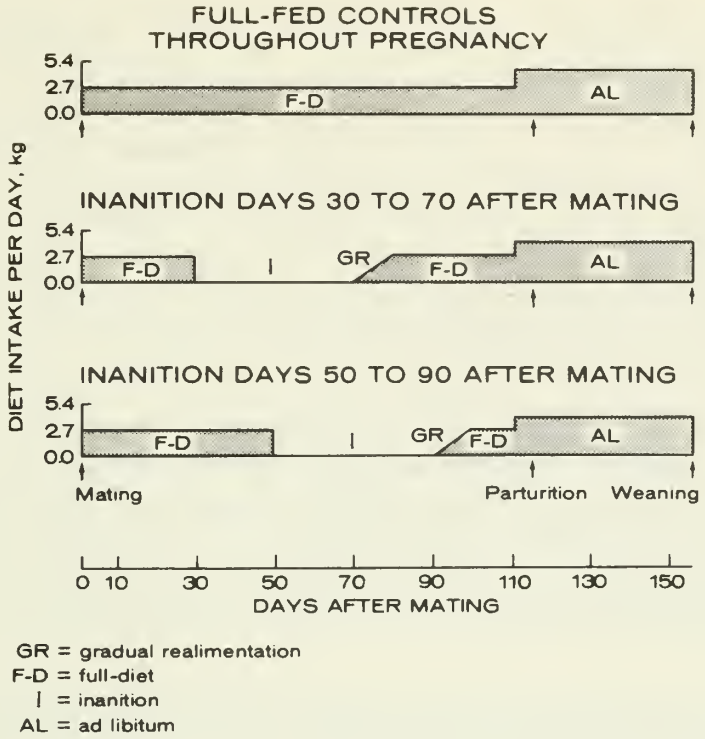

Figure 7. Description of experimental and control groups of pigs indicating day of mating, parturition, weaning, treatment periods, and daily level of food intake. Abbreviations are: F-D, full diet; Al, ad libitum; I, inanition; and GR, gradual realimentation. Hard and Anderson, 1979a.

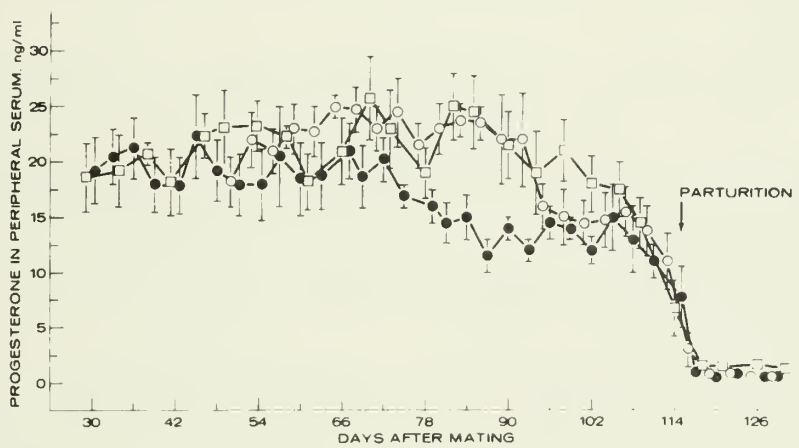

Figure 8. Progesterone concentrations (ng/ml, mean ± SE) in peripheral blood serum during pregnancy and lactation of a) 6 pigs given a full diet throughout gestation (□), b) 6 animals subjected to inanition days 30-70 (●), and c) 6 animals subjected to inanition days 50-90 (○). Hard and Anderson, 1979a.

Maternal blood serum levels of progesterone in the starved gilts were maintained at concentrations similar to those in full-fed controls (Fig. 8). Progesterone concentrations in the controls remained at a level of 18 to 25 ng/ml from *day 30* until approximately *day 105*, when the concentrations began to decline, reaching basal levels at parturition and remaining at these levels through *day 130* after mating. The progesterone concentrations of the dams starved during the middle third of pregnancy (closed circles) were similar ($P>0.05$) to those in full-fed dams during the 40 days inanition period ending *day 70*. From *days 72* to *99*, however, progesterone levels of these dams were reduced ($P<0.01$) to a mean value

of 14.5 ng/ml. This reduction in serum steroid levels occurred after the starvation period and during gradual realimentation and full-feeding. By *day 100* progesterone levels in this group were again similar to the levels in controls and remained so through *day 130*. Progesterone levels of dams starved during the last third of pregnancy (Fig. 8, open circles) remained similar to those of full-fed controls throughout gestation. Thus, progesterone concentrations in both experimental groups remained at levels sufficient to sustain pregnancy. These experimental results indicated that maternal nutrient deprivation during the middle third or last third of gestation has little effect on ovarian progesterone secretion and is not a major limitation to fetal survival in this litter-bearing species.

Prolonged starvation in these gilts markedly reduced birth weight of living neonates (Table 4). Growth of the neonates also was reduced to 80 days of age, when they weighed 7 kg less, on the average, than the offspring of the control dams. Body weight at 150 days of age, however, was similar ($P>0.05$) in all experimental and control groups. Litter weight of live piglets at birth was similar among all treatments, primarily as a result of the larger litters born to the starved dams.

Reproduction in Yorkshire Gilts Born to Dams Starved During Pregnancy. After weaning, gilts born to dams that had been starved during the middle third or last third of gestation and gilts born to full-fed control dams were raised in the same outdoor lot. At approximately 150 days of age these gilts were checked for estrous behavior by a fertile boar and allowed to mate at the third confirmed estrus. Reproductive performance through the first two gestations was evaluated in a random selection of gilts born to each experimental and control group (Hard and Anderson, 1979b).

Age at pubertal estrus was reduced ($P<0.01$) in gilts born to dams starved during pregnancy. Control gilts exhibited first estrus at an average age of 250 days whereas gilts born to dams starved during the middle or last third of pregnancy displayed pubertal estrus at 208 and 219 days, respectively. Fifteen of 18 gilts born to starved dams from both experimental groups, mated at the third postpubertal estrus and remained pregnant to term. First-parity birth weight of living neonates from gilts born to dams starved during pregnancy were similar to birth

Table 4. Reproduction in Pigs Subjected to Inanition During Middle or Late Pregnancy on Litter Size, Birth Weight and Neonatal Growth

	No. of pigs mated/ delivery*	Litter size at birth	Individual living piglet birth wt., kg	Litter wt. at birth, kg	Body wt. at 80 days of age kg
Full-diet control	6/6	8 ± 1.5†	1.6 ± 0.05†	12.4 ± 1.95†	26.9 ± 1.66§
Inanition *days 30* to *70*	12/10	9 ± 0.9†	1.2 ± 0.03†	9.5 ± 0.92†	19.9 ± 1.66†
Inanition *days 50* to *90*	11/7	10 ± 0.8†	1.0 ± 0.03§	10.7 ± 0.82†	20.4 ± 1.66†

Values are means ± SE. Means within column with different superscript are different at $P<0.05$ level of significance. *Chi-square = 3.317, df = 2, ($P<0.05$). Hard and Anderson, 1979a.

weights of living neonates from controls. First-parity litter weights at birth also were similar among all groups. Litter size at birth of first-parity living neonates averaged 7.9 in gilts born to starved dams and was similar ($P>0.05$) to that (9.4 piglets) in gilts from full-fed controls. Second parity pregnancy rates, birth weights, litter weights, and litter size at birth and weaning were similar for all gilts born to starved and control dams.

Conclusions. Considerable reproductive potential is not realized, primarily because of approximately 40 percent embryonic and fetal death in normal, healthy gilts and sows. This report concerns the roles of maternal nutrition and ovarian hormones on fetal survival in this species. Other investigations have indicated that high-energy diets increase slightly the number of eggs released at the time of mating, but that a continuation of high energy intake throughout gestation results in increased fetal losses. Slight restriction of energy intake during gestation has no detrimental effects on litter size. It is well established that progesterone secretion by the corpora lutea in the ovaries is essential throughout pregnancy in this species. Although these same corpora lutea accumulate and secrete relaxin in late stages of pregnancy, the physiological actions of this polypeptide are less well known.

The experiments reported here describe the interaction of ovarian progesterone secretion and maternal nutrition on fetal development and neonatal survival. The young gilts used in this study were growing, and the available nutrients would be required for fetoplacental growth as well as maternal growth. During early pregnancy daily injections of progesterone sustain embryonic development in nutritionally deprived dams. The experimental results clearly indicate that ovarian progesterone secretion is maintained at near normal levels in gilts subjected to prolonged starvation during either middle or late pregnancy, and furthermore, neonatal survival rates are equivalent to those found in full-diet controls. Fetal growth in these starved dams is affected adversely and results in markedly reduced birth weight and neonatal growth.

Maternal components are mobilized for fetoplacental growth in spite of severe loss of body weight by the dam. Placental growth and function depend on adequate blood serum levels of progesterone, and placental insufficiency during prolonged starvation results in either reduced fetal growth or abortion in only a few of the dams. It is evident that inadequate maternal nutrition during relatively brief segments of gestation is not a major limitation to ovarian progesterone secretion and fetal survival in this litter-bearing species. The mechanisms of progesterone's actions in sustaining fetoplacental development in this species require further investigation. These experimental approaches provide appropriate models for elucidating those steroid mechanisms that have an important influence on fetal survival in this economically important species.

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Long-Term Sow Productivity

J.F. O'GRADY

In European pig production it is standard practice to keep breeding sows in the herd for as long as is consistent with an acceptable level of performance. Clearly this period will vary greatly between herds. It may range from an average of less than three litters per sow to more than six and appears unrelated to herd size, lactation length, and breed of sow (Dagorn and Aumaitre, 1979).

The general trends in different countries are similar, as seen from Table 1. In Denmark, Ireland, France, Netherlands, and Yugoslavia average number of litters produced per sow before culling is between four and five while in all these countries it is necessary to cull about 20 percent of sows after the first litter. Equally, only about 20 percent of sows produce more than six litters, despite the fact that some animals produce 12 or more viable litters.

Reasons for culling are varied but failure to come into estrus or to conceive is the largest category as seen from French data in Table 2.

It will now be apparent that a system of sow keeping that aims at multiple parities from most animals presents many problems. The question must therefore be asked if such a system has economic advantages over an all-gilt system? The Dutch authors Kroes and Van Male (1979) have examined this problem. Their findings are in Table 3. As far as possible all costs were taken into account and they show clearly that the cost of producing a 22-kg pig is greatest in the first litter. The cost declines to the third litter and gradually increases from there onwards. When the cumulative cost is computed it is shown to be least if the sow produces seven litters before being culled. There is little disadvantage, however, from keeping the sow longer in the herd.

The increase in cost per piglet in fourth and subsequent litters shown in the Dutch data can be explained partly by the cull value of the sow but also by the number of pigs weaned per litter. Table 4 presents data recently computed by my colleagues Lynch and Kearney from 846 litters farrowed in the Moorepark herd between January, 1977 and August, 1978. While the total number of pigs born per litter increased up to the ninth litter there was a dramatic increase in stillbirths after the fifth litter and numbers weaned per litter peaked at the fourth litter. Further study of the above data shows that no change would occur in average number weaned per litter if all sows were culled after the seventh litter. Were it possible to increase performance in the first litter, the overall average would be improved from culling older sows.

Although one can consider this type of selective culling, it is clear that high culling rates generally lead to poor performance. Dutch data (Table 5) based on 15,000 services in 85 commercial farms and French data (Table 6) based on 135,426 litters in 1049 commercial herds show an advantage of 1-1/2 to 2 pigs per year in favour of the herds with low culling rates.

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Any attempt to minimize culling must examine the causes of culling and also pay particular attention to the 20 percent of sows that are culled after the first litter. Yugoslav data were analyzed to examine the effect of age of gilt at first conception on lifetime productivity. The results are shown in Table 7. They show a clear advantage from delaying first mating until the gilt is older than 8 months. It is interesting that this agrees with survey data published by Pomeroy (1960), who found that gilts younger than 8 months when mated for the first time had lower lifetime performances. Results of an experiment at the Rowett Research Institute, on the other hand, do not show such a trend (MacPherson *et al.* 1977). This experiment was not designed to examine culling rates, however, and the paper does not state what weaning to mating interval was acceptable before culling. Both the Yugoslav and the Pomeroy reports conflict completely with the concept of early mating proposed by Brooks (1979) and others.

In the Moorepark herd gilts have been mated at a wider range of weights than those used by either Brooks or MacPherson *et al.* Some data from these matings have been assembled recently and are presented in Table 8. These data show the expected increase in numbers born with increased mating weight. They also show a marked effect on average piglet birth weight and on survival among piglets so that the differences were much greater in numbers weaned than in numbers born. The effect on birth weight was present in the experiment of Brooks and Cole (1973) but did not reach significance.

This effect was not present in the Rowett experiment but birth weight may have been influenced by the lower pregnancy weight gains of the heavier gilts. As of now I can only say that to me there appears to be perhaps more evidence against early mating than for it and in the context of long-term high level performance it is my experience that early mated gilts present many herd problems.

Factors influencing weaning to mating intervals. Survey data show that the major cause of low productivity in sow herds is delayed mating after weaning. Table 9 shows the theoretical numbers of litters per sow per year. In practice about one-quarter of a litter less is achieved (Ridgeon, 1976), depressing sow output by over 2 pigs per year. The pattern in a high output herd is seen in Table 10 and this may be contrasted with the pattern found commercially in France (Table 11). The problem of delayed return to estrus is most pronounced after the first lactation and two factors in particular have been demonstrated as involved. These are level of feeding after weaning and level of crude protein fed in lactation. Brooks and Cole have documented the former, as set out in Table 12. They show a response not only in reduced weaning to mating interval but also in increased litter size and in increased farrowing rate.

Other workers (O'Grady 1972, Brooks *et al.* 1975) have examined level of feed following weaning of multiparous sows and have found no effect.

O'Grady and Hanrahan have shown that protein level fed in the previous lactation influences the weaning to mating interval (Table 13). Although it is difficult to interpret such data because of their high variability, the indications are that the shortest weaning to mating intervals and the lowest culling rates follow levels of 12 to 14 percent crude protein and 0.6 to 0.8 percent lysine. It is also interesting to note that the delayed estrus following low protein feeding occurred only after first and second litters. Thus it appears that protein requirements decrease with age of sow.

Long-term energy nutrition. Joint studies on the energy requirement of the lactating sow were undertaken at Moorepark and the Rowett Institute and published by O'Grady, Elsley, MacPherson, and McDonald (1973, 1975). Milk yields and composition were determined as were litter performances and weight changes of the sows. The energy levels fed in lactation ranged from 12.2 to 18.25 Mcal DE (3.7 to 5.5 kg. U.S. type feed equivalent) per day for gilts; 12.9 to 19.6 Mcal DE (3.9 to 5.9 kg.) for second lactation; and 13.2 to 20.25 Mcal DE (4 to 6.1 kg.) for third lactation sows.

An interesting point to emerge was that in the first lactation the yield and composition of milk and growth of litters were not influenced by dietary energy intake. In the second lactation milk yield was depressed by lower energy intakes and this was reflected in litter weights at 21 days though not at 42 days. In the third lactation lower energy intakes seriously depressed milk yield. On the lowest energy level, milk yield was 32 percent lower at day 24 and 20 percent lower at day 41 of lactation than on the highest energy level. The corresponding depressions in litter weights were 17.2 and 13.5 percent at 21 and 42 days respectively.

One could perhaps argue that lower milk yield could be compensated for by increased creep feed intake. Body condition of the sows, however, was more striking. At the lower energy level sows were extremely thin, and on slaughter and dissection after the third lactation were seen to have very little subcutaneous fat. Comparisons with maiden gilts slaughtered at mating weight showed the lowest energy group to have lost nearly 80 percent of the weight of subcutaneous fat they had as gilts. An energy balance computed from the dissected tissues indicated that although animals on the three higher energy levels had gained carcass weight, only the highest group had more carcass energy reserves (9 percent more) than the maiden gilt carcasses. Energy reserves of the lowest group amounted to only 58.5 percent of that in the maiden gilt carcasses (Table 14).

This experiment demonstrated that energy balance is vital in long-term sow keeping while the effects of depletion may take three parities to be noticeable. This is the opposite to the effects of protein shortage, which are most pronounced in the gilt.

High energy levels of feed do not involve a great usage of sow feed over the reproductive cycle. Assuming a 5-week lactation and 2.25 litters per sow per annum, the total feed amounts to 1.04 metric tons/sow/year. With higher density U.S. type diets this will be reduced to about 0.95 metric ton.

This level of sow feed, if combined with high sow output and efficient feeding systems during rearing and finishing, results in a total feed usage of less than 4 kg. of feed per kg. of deadweight pig sold in the Moorepark herd where the finishing diet (30-82 kg. liveweight) is based on barley and soybean meal.

Table 1. Pattern of Sow Culling in Different Countries

Litter No.	Country and reference				
	Denmark (Rosbach, 1969)	Ireland (Lynch & Kearney, 1979)	France (Dagorn & Aumaitre, 1979)	Netherlands (Kroes & Van Male, 1979)	Yugoslavia (Miskovic *et al.*, 1977)
	Pct. culled after each number of litters				
1st	21.6	19.1	21.2	19.6	28.7
2nd	16.9	5.4	15.4	16.3	12.7
3rd	11.0	20.6	12.8	13.8	7.7
4th	8.7	0.0	11.2	11.6	6.8
5th	13.1	17.2	10.0	9.9	5.3
6th	9.9	12.8	8.9	8.6	6.9
7th	7.1	3.9	7.4	7.0	6.3
8th	6.0	8.8	5.4	5.3	5.5
9th	1.2	1.5	3.6	3.7	6.8
10th and 10+	4.6	10.3	4.1	4.2	13.3
Avg. litters/sow	4.0	4.9	4.2	4.6	4.5

Table 2. Reasons for Culling 52,800 Sows in France

Reason	Pct.
Failure to breed after 1 or several matings	31.0
Decrease in productivity with age	27.2
Leg problems	8.8
Low farrowing and weaning performance	8.4
Death on farm	6.5
Anestrus	5.4
Farrowing difficulties	4.0
Abortion	2.8
Miscellaneous	5.9

After Dagorn and Aumaitre 1979

Table 3. Cost of Producing a Piglet (22 kg) in Consecutive Litters (DF1)

Litter No.	Cost/piglet (D. Gu.)	
	In litter	Cumulative
1	135.4	135.4
2	109.8	122.9
3	101.6	116.6
4	102.3	113.8
5	105.8	112.6
6	106.2	111.9
7	109.5	111.7
8	112.1	111.8
9	114.4	112.0
9	113.5	111.9

After Kroes and Van Male 1979

Table 4. Influence of Parity Number on Sow Performance

	Parity no.										
	1	2	3	4	5	6	7	8	9	10	10+
No. of litters	173	140	130	95	96	65	43	36	21	19	28
Born/litter	9.3	9.7	10.6	11.2	11.2	11.2	10.4	12.2	12.7	11.0	11.7
Born alive	8.8	9.1	10.0	10.3	10.4	10.0	9.3	10.8	10.4	9.0	9.3
Stillbirths (pct.)	5.7	5.7	6.0	7.6	6.5	11.2	11.0	11.7	18.0	18.1	20.5
Birth weight (kg.)	1.36	1.58	1.59	1.55	1.57	1.53	1.57	1.42	1.39	1.45	1.42
No. weaned/litter	7.1	8.7	8.7	8.9	8.8	8.6	8.3	8.5	8.2	8.4	8.2

Source: Lynch and Kearney 1979

Table 5.--Relationship Between Culling Rate and Sow Output in Dutch Herds

	Culling rate		
	Low	Average	High
Litters/sow	6.56	4.55	3.42
Replacements/yr. (pct.)	31.3	43.4	55.4
Litters/sow/yr.	2.06	1.97	1.89
Weaners/sow/yr.	17.9	17.1	16.4

Source: Kroes and Van Male 1979

Table 6.--Relationship Between Culling Rate and Sow Output in French Herds

	Litters/culled sow				
	<3	3-3.99	4-4.99	5-5.99	6+
Weaned/litter	8.25	8.53	8.51	8.61	8.71
Weaned/sow/yr.	15.5	16.5	16.7	17.1	17.6

Source: Dagorn and Aumaitre 1979

Table 7.--Effect of Age of Gilt at Fertile Mating on Culling Rate and Litters Produced

Age at fertile mating (months)	No. of gilts	Percentage culled after litter no. 1	2	1-6 inc.	Litters to culling
7.0 - 8.0	350	29.1	16.0	86.8	3.65
8.5 - 10.0	319	20.4	10.3	65.8	5.08

Source: Jovic *et al.* 1975

Table 8.--Effect of Gilt Weight at Fertile Mating on First Litter Performance

	Weight at mating (kg.)						
	90	100	110	120	130	140	<170
No. of gilts	12	33	48	25	25	11	8
Born/litter	8.2	9.4[a]	8.8	9.6	10.2	10.2	9.9
Stillbirths (pct.)	4.9	4.3	6.8	4.2	7.8	4.9	0
Avg. birth wt. (kg.)	1.18	1.25	1.31	1.41	1.47	1.51	1.66
Weaned	5.8	5.6	6.9	8.0	8.4	8.4	9.3
Avg. weaning wt. (kg.)	5.8	6.4	6.2	6.4	6.9	7.1	7.3
W-Service (days)	8.5	10.3	10.0	8.4	9.3	7.1	5.8

(a)One gilt farrowed 20 pigs.
Source: Lynch and Kearney 1979

Table 9.--Weaning Age and Potential Litters per Sow per Year

Weaning age (weeks)	Possible litters per year	Days available for weaning to conception
3	2.5	10
4	2.4	9
5	2.3	8.5
6	2.2	8.5

Table 10. Pattern of Returns to Service in the Moorepark Herd

Days after weaning	Sows in estrus	
	No.	Pct.
0(a)	9	1.3
3	8	1.1
4	90	12.7
5	359	50.8
6	100	14.1
7	35	5.0
Total for days 0-7	...	85.0
8-14	63	8.9
15-21	18	2.5
21+	25	3.5
Total for days 8+	...	14.9

(a)Mostly mated during suckling.

Table 11.--Pattern of Returns to Service on French Farms

Days after weaning	Pct. of sows mated
1 to 14	58.5
15 - 20	5.5
21 - 30	9.5
31 - 40	8.5
41 - 50	6.8
Over 50	11.2

Source: Legault, Dagorn and Tastu 1975

Table 12.--Influence of Feed Level After Weaning First Litters on Weaning to Mating Intervals

	Amount of feed (kg./day)		
	1.8	2.7	3.6
Weaning to mating (days)			
Average	21.6	12.0	9.3
Range	4-39	4-18	3-21
Piglets born/litter	9.4	10.1	11.6
Farrowing rate (pct.)	58.3	75.0	100.0

After Brooks and Cole (1972)

Table 13.--Influence of protein Level Fed in Lactation on Weaning to Mating Intervals

Crude protein level (pct.)	9.3	9.3	11.8	4.3	11.8
Lysine level (pct.)	.43	.58	.62	.81	.78
Days from weaning to mating following:					
Lactation No. 1	29	18	14	9	14
Lactation No. 2	12	14	7	7	7
Lactation No. 3	8	6	9	5	5
Sows weaning 4th litter (pct.)	63	58	67	80	71

After O'Grady and Hanrahan (1975)

Table 14.--Estimated Energy Content of Gilt Carcasses and of Carcasses From Sows Given Different Energy Allowances in Three Consecutive Lactations

Type of carcass	Energy level (Mcal)
Gilt	308
Sows	
Low energy level	180
Medium energy level	206
High energy level	247
Very high energy level	336

Source: O'Grady, Elsley, MacPherson and McDonald (1975).

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Health Problems Associated With Swine Reproduction

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The impact of disease and poor health on swine reproduction can be devastating to any scheme of production. This is especially true of current intensive production methods as they are applied to semi-confined and totally confined production. The rapid intensification of production and confinement has stimulated new interest in researching the normal physiology of reproduction in swine as well as the disease processes which alter normal physiology. To some extent, the research has lagged behind the needs of the swine industry as it has rapidly changed, generating many problems for which there have been no answers, yet demanding answers in the face of the economic disasters that occur when reproduction fails to meet the projected standards.

The common ground of understanding for producers, animal scientists, nutritionists, veterinarians, and all others who touch swine reproductive efficiency is that the problems are complex. It must be emphasized that any single agent, acting alone, rarely produces a disease problem in reproduction. It must also be stressed that infectious agents alone are seldom the only thing involved in a herd reproduction problem. When we try to analyze a herd reproductive problem we must investigate and search through a whole host of infectious and noninfectious possibilities. Experience tells us that noninfectious factors such as ignorance, management error or laxity, genetically linked abnormalities, nutritional mismanagement, and adverse environment are the more common causes of reproductive failure.

What is reproductive failure or inefficiency? It is the failure of a fertile female pig to produce a satisfactory number of piglets, born alive, at 114 days after proper service by a fertile boar with normal semen, and to nurse the progeny adequately until they are weaned. The definition involves many aspects of reproduction, including survival to weaning. It requires a fertile female and male and an ability to conceive, gestate, bear offspring, and care for them until weaned, and in intensive production it demands that the process be repeated as rapidly as possible.

The major factors that complicate reproduction in the pig are:

1. Genetics
2. Nutrition
3. Environment
4. Toxins
5. Infections
6. Management

Infection as it applies to health problems in reproduction will be the principle thrust of this presentation. Infection is a word that has been common to all of us for most of our lives, yet the meaning of the word is not always well

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understood. It is defined as invasion of the tissues of the body by pathogenic organisms in such a way that injury followed by reactive phenomena results. An infectious disease is one caused by viruses, bacteria, parasites, and fungi, and it may or may not be contagious. Infection is not synonymous with disease. Many infections may occur and produce a reaction but no identifiable clinical disease. Many different microorganisms have been isolated from, and blamed for, reproductive disorders, yet relatively few of these disorders can be convincingly reproduced. Many organisms naturally reside in normal-appearing pigs as well as in their environment. An upset in the balance of these organisms by factors such as poor nutrition, stress, antibiotics, and other factors can be reflected in an observable clinical disease.

The principal effects of infection occur at breeding and conception and during gestation in the female.

Infection can reach the uterus by two avenues: (1) through the vulva and ascending into the uterus; (2) by way of the blood stream. Infections that enter by way of the vulva tend to produce their effects early in gestation rather than later. Those entering by way of the blood stream may have their effects at any time. Damage to the reproductive tract can be identified by:

1. Lack of conception after breeding with return to heat at the proper time
2. Lack of conception after breeding with return to heat later than the proper time
3. Abortion
4. Mummies
5. Stillborn pigs
6. Weak and underdeveloped live pigs at birth
7. Small litters
8. False pregnancy

VIRAL INFECTIONS

Much confusion surrounds viral infections. Their effect depends on the following:

1. Stage of pregnancy
2. Exposure dose of virus
3. Frequency of exposure
4. Route of exposure
5. Immune state of the animal
6. Conditions of existence (stressed, unstressed)

The common viruses affecting reproduction are:

1. Picornaviridae - Enterovirus (SMEDI)
2. Parvovirus

3. Pseudorabies
4. Hog cholera
5. Influenza virus
6. Cytomegalovirus - inclusion body rhinitis
7. Reovirus and adenovirus
8. Congenital tremors virus
9. TGE
10. IBR
11. Japanese B. encephalitis virus (Sendai)

Picornaviridae - Enterovirus (SMEDI)

This has been a "wastebasket" for diagnosis of reproductive failure. A diagnosis of SMEDI can be made yet practically never verified; therefore it is used as a "crutch" when no other cause can be found.

Eight serogroups are supposed to be present in this country. Four of the eight have at least one serotype that can cause reproductive failure characterized by stillbirth, mummification, embryonic death and infertility. The route of infection is by the mouth or nasal passage, or possibly through venereal infections, and then to the blood stream.

Diagnosis is difficult because all swine of breeding age have a serum titer to at least one and sometimes all of the serogroups. Tests are not routinely run by diagnostic laboratories. Diagnosis must be based on accurate history of the problem, careful evaluation of clinical signs, and elimination of other possible causes.

Control measures for SMEDI include:

1. Communal exposure
    a. Across the fence
    b. Rotation of pens
    c. Moving fecal material from one pen to another
    d. Comingling of sows and gilts
    e. Retaining immune animals
2. Closed herd
    a. Isolating new introductions

Parvovirus

About 80 percent of adult swine have a serum titer for parvovirus indicating that they have had an experience with the disease. However, less than 50 percent of market weight gilts possess a titer for parvovirus.

This virus has a predilection for rapidly dividing cells (fetal cells). The route of infection is by the mouth or nasal passage, or possibly through venereal infection, and then to the blood stream.

The clinical signs are the same as for enterovirus SMEDI and are highly dependent on the stage of gestation. In sows or gilts in the first 3 weeks of pregnancy the most common signs are a poor conception rate with delayed returns to heat (25 to 35 days). Parvovirus infection occurring at 22 to 40 days of pregnancy can result in resorption of the embryo with a false pregnancy and failure to return to heat until 120 to 130 days of "gestation" have passed. Infection occurring at 40 to 70 days may produce mummies, stillborns, and weak pigs at birth with an occasional abortion. Since the fetus becomes able to produce an immune reaction at about day 70 of fetal development it is not likely that parvovirus will have any effect on the litter past day 80 of gestation.

Diagnosis of parvovirus can be made by fluorescent antibody staining procedures on mummified or stillborn fetuses. Serum samples can be taken but are usually of little diagnostic value unless two are taken and a significant difference in titer is found.

Control and prevention measures are the same as for enterovirus reproductive failure.

Pseudorabies

The reproductive problems associated with pseudorabies virus are similar to those of enterovirus and parvovirus. In severe pseudorabies infections the sow or gilt becomes sick and may be unable to maintain pregnancy because of systemic illness. At the height of initial outbreaks, especially with the more virulent strains of the virus, there will be abortions, weak pigs, and many pig deaths as well as very low conception rates and minimal sexual activity by both females and males of breeding age.

Pseudorabies diagnosis can be made by a combination of careful herd observation, testing of serum samples, fluorescent antibody examination of selected tissues, and virus isolation attempts.

Pseudorabies control measures include vaccination and allowing herd immunities to become established.

Influenza virus

This virus basically has an affinity for lung tissue. It produces a profound illness, with sudden onset and pneumonia, but most animals make a fairly rapid and complete recovery. Systemic illness in a pregnant sow could result in inability to maintain pregnancy. In addition, mating activity may cease at the height of the illness. There is considerable evidence that influenza virus does *not* produce severe reproductive failure problems in swine breeding herds.

Diagnosis is made by observing clinical signs and following the course of the disease. Blood testing can be done but may not be significant because a high percentage of swine may have circulating antibodies anyway. High titers in the absence of other positive diagnostic tests might be significant.

Cytomegalovirus

This virus is usually associated with moderate to severe upper respiratory disease in baby pigs 1 to 3 weeks old. It has been associated with a slight increase in stillborns and weak pigs at birth.

TGE virus

There is no direct clinical evidence that TGE causes reproductive failure. Reproductive efficiency may decrease during and following an outbreak, probably because of a disruption of the breeding program or an indirect effect on maternal health.

Congenital tremors virus

This virus can be transmitted *in utero* to baby pigs. Clinical signs are splayleg, mild to violent muscular tremblings, and weak pigs. Some pigs die from starvation and from being lain on. No direct effect on reproductive disease has been identified.

Hog cholera, IBR, Japanese B encephalitis virus, reovirus and adenovirus

Either these viruses are not present in the United States or their significance has not been well established.

BACTERIAL INFECTIONS

Bacterial infections affecting reproduction in swine include:

1. Brucellosis
2. Leptospirosis
3. Eperythrozoonosis
4. *Escherichia coli, Salmonella, Corynebacterium, Staphylococcus, Streptococcus*

Brucellosis

In the United States the incidence of this disease in swine has declined to the point where clinical cases are uncommon. In an Iowa survey only 0.002 percent of serums tested in a year were positive. The cause of brucellosis in swine is the bacterium *Brucella suis*.

Regulations that require breeding swine to be tested before sales, shows, and interstate movement provide continuous monitoring, allowing early recognition of infection in a breeding herd.

Some signs of this disease are:

1. Early death of the embryo
2. Weak pigs and stillbirths
3. Sterility, especially in the boar
4. Inflammation of the lining of the uterus (endometritis)
5. Inflammation of the fertilization tube (oviduct)
6. Chronic inflammation of joints, especially those of the back
7. Chronic inflammation of the testes and male accessory glands

Federal and state regulatory action is taken where brucellosis is identified in a herd. There are programs which when initiated and completed can eliminate this disease from a herd while preserving the genetic material in the herd.

Leptospirosis

Leptospirosis is caused by a spirochete. There are 18 serogroups and 124 serotypes. The serotypes demonstrated to most commonly affect swine are *Leptospira pomona, L. grippotyphosa, L. canicola,* and *L. icterohemorrhagica.*

Of these serotypes, *L. pomona* has been proven to cause clinical signs. There is sufficient circumstantial evidence to strongly implicate the others.

The infection is not usually apparent in nonpregnant swine. The most common signs are abortions in the last two or three weeks of pregnancy. Acute lepto infection usually precedes the observed effect (abortion - reproductive failure) by two to three weeks. The infection localizes in the kidney, and organisms capable of infecting other pigs are shed in the urine for up to six months.

A diagnosis can be based on clinical signs and tests of blood samples from affected animals. Culture attempts of aborted fetuses can be made but the fetuses *must be fresh.* Urine samples from affected females can also be examined for the organism.

This disease can be controlled quite effectively by use of vaccination. At present multivalent bacterins (bacterins containing five different serotypes) are commonly used. Gilts should be vaccinated before breeding and sows every time they go through the farrowing crates.

Eperythrozoonosis (EPE)

The causative agent is a rickettsia named *Eperythrozoon suis.* which enters the red blood cell and destroys it.

The reproductive problems associated with this disease are insidious and poorly defined. Problems that occur may be seen in many other diseases. Most frequently reported are:

1. Delayed estrus
2. Early death of the embryo
3. Increase in repeat breedings
4. Pregnancy rates as low as 30 percent in exposed animals
5. Occasional abortion in late gestation

Transmission is not direct. Lice, possibly mange mites, mosquitoes, and blood-contaminated equipment such as tail cutters, injection needles, and castration instruments provide many opportunities to carry the infection from animal to animal.

Totally effective control methods have not been formulated. It is obvious that mange and lice must be eliminated and processing instruments properly disinfected between pigs. Treatment programs using arsanilic acid and tetracylines have been helpful.

Miscellaneous bacterial infections

Bacterial infections due to *Escherichia coli, Salmonella, Corynebacterium, Staphylococcus, Streptococcus,* and other organisms have not been well demonstrated

as a specific cause of reproductive failure in swine. It is known that bacterial contamination of the reproductive tract can prevent conception or create conditions in the uterus of such extent that the embryo cannot become implanted.

When bacterial infections are suspected, the following measures should help to control them:

1. Sanitation of animals and facilities. This includes keeping bed or crates clean, cleaning and disinfecting gestation quarters, providing equipment that does not enhance possibilities for bacterial contamination.
2. Flushing posterior portions of the reproductive tract with specific antibiotics based on culture and sensitivity testing.
3. Addition of therapeutic levels of effective antibiotics in the feed at breeding time and one week pre-farrowing.

HEALTH MAINTENANCE

Maintenance of the health of the animals in a swine production unit is an essential goal if cash flow and other economic factors are to be satisfactory. There is plenty of room for improvement in most herds. Health maintenance requires:

1. Effective, well planned, and well executed preventive programs
2. A comfortable, low stress environment
3. Attention to detail by management
4. Monitoring the health status of the herd on a regular basis
5. Well kept, accurate records
6. Targets based on records
7. Analysis of records
8. Utilization of a regular and knowledgeable veterinary swine health service that identifies health problems, analyzes health records, monitors the herd, understands the epidemiology of the important economic diseases, and makes recommendations based on all of the above.

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Labor Incentives in Swine Production

C.J. HEIDENREICH

For all of us engaged in swine production, the problems of labor have become increasingly important in recent years. Briefly stated, this can be ascribed to (1) the increasing cost of labor, so that it represents a larger share of our production costs; and (2) the difficulty in locating, hiring, and retaining adequate labor to staff the large production units evolving in the industry.

For over twelve years, we at the University of Wisconsin-Platteville have been attempting to alleviate the problem of labor shortage by developing and offering a swine management program. Some of you have hired our students as well as helped train them through participation in our internship program. I wish to personally thank you for your interest and help. However, we all realize we have a long way to go before a solution is forthcoming.

In order to better understand the nature of the problem, we at the University of Wisconsin-Platteville have conducted a follow-up study of our graduates over the past twelve years. The study covered all graduates of the College of Agriculture who earned four-year degrees between 1967 and 1978. Eighty-two percent of these students originated on farms. The majority of them (80 percent) were from Wisconsin. The remainder were from Illinois (12 percent), Iowa (6 percent), and other states and foreign countries (2 percent).

Initial occupations of graduates were almost entirely in agriculture (95 percent) with the largest single category returning to the farm (21 percent). An additional 7 percent secured initial employment as farm/livestock managers, with approximately 4 percent or 35 individuals being employed in swine production. Of those returning to the farm, a number were involved in varying levels of swine production ranging from part-time to primary farm enterprise units. A number of students who had intended to enter swine production careers upon graduation deflected to other agriculture-related positions due to more favorable offers (as perceived by the student) at the time of graduation. In this regard, starting salary was often a determinant. Shown below are the median starting salaries of all graduates. The highest was $17,000.

Year of graduation	*Median starting salary*
1967 through 1969	$ 7,780
1970 through 1972	7,960
1973 through 1975	9,333
1976 through 1978	11,500

In most cases, the starting salaries (including fringe benefits) in swine production careers were below the mean of the year represented.

The pattern of acceptance of initial occupation has changed very little during the period of the study. The number returning to the farm and taking positions

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in farm/livestock management has fluctuated the most. The fluctuations in these categories are indicated below.

	Year of graduation				
	'67-'69	'70-'72	'73-'75	'76-'78	$\bar{x}$ (weighted)
Farming and farm/livestock manager, pct.	22	29	37	22	28

The majority (62 percent) of graduates during the period of this study remained in occupations related to their initial employment. The career retaining the most graduates was farming (81 percent) while farm/livestock management retained the least (35 percent). Further derivation of statistics on the 35 individuals previously cited as initially entering swine production careers translates to 12 remaining employees, of whom the majority are graduates of the most recent years. An initial conclusion would suggest that our training of swine production employees has been of very modest success. It must be noted, however, that more than half of those leaving swine management positions eventually operate their own farms, most of which are engaged in swine production.

It appears that a relatively high degree of disenchantment existed with initial careers in swine management. The survey indicated that although dissatisfying work and insufficient financial rewards were important, lack of advancement opportunity was the most often cited reason for leaving. None of the students reported a lack of training or inability to perform assigned tasks as a factor in their resignation. In fact, over 80 percent of all agriculture graduates reported good to excellent preparation for initial employment.

There is no doubt that the type of work involved in swine production management often is dissatisfying, especially as practiced in the larger total confinement facilities. Most students graduating are highly motivated. The "upward mobility" afforded by an education remains a significant part of the psychological make-up of agricultural students. "Upward" in more recent years has come to encompass improved life-style as well as improved financial status. "Quality of life" has become increasingly important to the young, highly motivated college graduate. In order to honestly assess the desirability of careers in swine management, we must take these factors into account. To state the problem more specifically, what are the incentives (the word is used here in its broad sense, being synonymous with motivation) needed to attract and retain employees? Apparently they are not adequate at present, or a labor deficiency would not exist.

Psychologists tell us that salary and financial incentives are not strong motivators. What employees need is recognition by peers and supervisors for work well done, a sense of achievement in their job, and growth potential. As perceived by the swine management employee, growth potential appears to be most lacking. Students generally expressed the concern that after a period of employment there appeared to be no further opportunity for growth. Probably most of them subscribe to the conscious or subconscious goal of owning their own swine enterprise as a growth potential goal. If such employees are to be retained, a partial ownership potential needs to be incorporated into the long-term employer/employee relationship. This must be understood at the initial stages of employment and a realistic timetable established and mutually understood and adhered to, providing the employee completes his obligations with a degree of proficiency that is clearly defined. As an example, the advancement sequence might be salary, including

fringe benefits; salary plus financial incentives; and finally salary plus a share of the ownership (and profit).

In the first phase, salary must be competitive. It is at this level that fringe benefits are important. A pleasant atmosphere in which to live and work is mandatory, especially for married employees. It may even be concerned with buildings designed for people as well as pig comfort (a compatability may exist). Salary and fringes are the starting point paid for basic labor input. This is essentially a *quantitative* input/output situation.

At the second level, financial incentives should begin to be implemented. Incentives must be realistic and potentially achievable, dependent upon the employee's efforts. Incentives are rewards for improvement in labor *quality* which result in increased productivity, and hence, net return. They should be related to traits that generally have low heritability estimates and are therefore most dependent on the level of management input for their realization (see Appendix).

The final stage, share ownership, should be initiated as soon as possible. Often it is an undue delay that precedes termination. Not all employees will reach this level nor are they desirous of this type of relationship. However, those that are qualified and desire such involvement must be identified and moved rapidly toward such a goal.

It becomes apparent that there are basically three levels of employment. Therefore, it is evident that three types of employees must be identified and properly placed. No single level of employment is the ultimate solution for all employees.

Dr. Beighley* has stated that each person has a "self-concept" which is well established in the young adult. Incidentally, neither we at the University nor you as employers have control over this self-concept. The individual comes to us with it well formed. I do feel, however, that the college graduate has often raised this self-concept. At least we like to think so! Job satisfaction depends upon the degree to which an individual actualizes or fulfills his self-concept. The position must provide an environment which permits each individual to implement or fulfill his self-concept. Since different people have varying self-concepts, they require varying levels of achievement and rewards. Unless an individual is in the level of employment compatible with his self-concept, dissatisfaction results through no fault of the employer. To repeat, job satisfaction depends on actualization of self-concept. As discussed earlier, a college graduate in swine management is usually highly motivated and has a self-concept that incorporates decision making and ownership objectives. Unless he moves to this level rather rapidly, job dissatisfaction ensues.

The question remains, wherein lies the solution to the labor dilemma in swine production? It may well be that employees (labor) should be recruited from alternate sources depending upon the position available and the ultimate level of employment anticipated. It is not implied, however, that an employee's origins should limit his ultimate level of employment.

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*Beighley, Kenneth E., Ph.D., Professor of Educational Psychology, University of Wisconsin - Platteville.

A. High school or vocational school graduates. These individuals often possess a self-concept which is more compatible with the level of labor (quasi-management) desired in some swine production facilities, especially where no eventual ownership potential exists.

B. College graduates (nonfarm background). We are seeing an increasing number of this type of student. Often they have a strong desire to work with livestock (swine) and lack any preconceived notions concerning the *modus operandi*. Our experience with this type of person has been relatively successful. These individuals fit in well when an uncertainty exists concerning the ultimate level of labor. Incentives seem to be effective with these individuals.

C. College graduates (farm background). These students are capable and often possess a self-concept which espouses an ownership goal. If the position offers this potential, the employee should be moved as rapidly as possible in that direction. Incentives are of only transient value in the retention of this type of individual. A long-term commitment may thus be realized. Otherwise, the employer will probably realize a limited-term commitment.

Increasing inputs of science and technology have led to our present intensity of swine production and made possible the development of large confinement enterprises. The time may have arrived when the scientific knowledge available about human motivation and job performance should be applied with equal precision to labor management in swine production.

APPENDIX A

A financial reward (incentive) based on the number of pigs weaned/litter is a desirable starting point in an incentive program. It is a trait with a low heritability (h^2 = ± 12%), hence is relatively responsive to the level of management.

Assuming that 11 hours of labor are needed to produce a litter of pigs at 40 lbs.* and that 8 pigs/litter are average, the labor cost (@ $4.00/hr.) per pig would be $5.50.

50 hrs./wk. x 50 wks./yr. x $4.00/hr. = $10,000/yr. salary
2500 hrs. ÷ 11 hrs./litter = 227 litters x 8 pigs/litter
= 1,816 feeder pigs/man/yr.

If nine 40 lb. pigs were produced per litter, it would amount to 227 additional pigs having a gross value of $6,810 (@ $30.00/hd.). The feed cost would increase about $1,362, whereas most other costs would not change significantly, leaving a net increase of $5,448 or $24.00/pig. If the employee were given an incentive of $5.00/pig (over 8) his salary would increase to $11,140. Ownership would realize a significant increase in net profit (or reduction in loss).

APPENDIX B

Other incentives have been suggested for various types of enterprises:**

Feeder Pigs Produced (For Sale or Fed out on the Farm)

25¢ - 50¢/pig weaned
$1 - $3/pig weaned above 7/litter
$3 - $5/sow that weans more than 8 pigs/litter
0.25% - 1% of gross income from hogs, including inventory changes

Feeder Pigs Purchased and Fed out

25¢ - 50¢/feeder pig bought and fed out
0.25% - 1% of hog sales less cost of feeder pigs

If death losses are less than 4%, the employee received 25% - 40% of the market value of these market hogs saved. (Example: 98% of feeder pigs purchased live to be sold on the market. The employee receives 25% - 40% of the market value of 2% of all market hogs sold.)

Complete Farrow to Finish Program

25¢ - 50¢/hog marketed during the year if employee stays until end of year
$2 - $5/market hog sold above 7/litter
0.25% - 1% of gross income from hogs--including inventory changes.

* "Farm Business Planning Guide", FM 6500, Cooperative Extension Service, University of Missouri, Columbia, Mo. 1965

** "Farm Business Arrangements", North Central Regional Extension Publication 50-1976, Extension Bulletin 401, Agricultural Extension Service, University of Minnesota.

Personnel Management: Structuring Your Farm Business to Include Employees

ALLAN G. MUELLER

Whenever two or more persons are involved in a farming venture, whether as co-owners or employer-employees, interpersonal relationships become a factor in the continued success of the business. Structuring the farm business among (1) legal entities for ownership purposes or (2) accounting entities for evaluating and rewarding labor and management performance is important to the continuity of the multi-person business.

The preceding participants in this session on Personnel Management will surely have mentioned equity ownership by employees, profit sharing incentives, and performance incentives. Our objective is to explore the legal and accounting entity structuring of your business as it relates to the multi-person unit. Joint ownership of equity implies sharing of residual earnings, after meeting the contractual expenses of the business entity. Profit-sharing incentive plans may or may not involve equity ownership but are highly dependent on a clear understanding of the meaning of "profits," a widely used term that is seldom defined and is ambiguous in its meaning to the casual user.

LEGAL STRUCTURING

The choice of legal entities includes: (1) proprietorships; (2) partnerships, including regular or limited partnerships; and (3) the corporate entity, with the choice of either the C or S chapter election to specify the way the corporate entity elects to report income for tax purposes. The scope of business activity and ownership of assets and liabilities is discretionary in the formation of a partnership or corporation entity. Once the legal entity is formed, however, legal statutes, legal contracts, and a variety of tax regulations control the decision options available to the equity owners and employees of the business. The consequences of the discretionary choices both before and after formation are explored later in this paper.

ACCOUNTING ENTITIES

The choice of the accounting entity or the unit of business activity in which we measure revenues, expenses, and income is completely open to the decision maker with one restriction. At some place in the accounting system, the boundaries of both the legal and the accounting entities must coincide. That is, the unit of accounting may include several legal entities, or several accounting entities (profit centers) may be delineated within one legal entity. In other words, the pie crust and the filling of the whole pie must be cut at the same place, but the user of accounting information is not restricted to just the one slice; nor is he required to eat all of a slice.

STRUCTURING THE BUSINESS FOR DIVIDING OWNERSHIP AND INCOME

The real world about the hog-producing industry provides several models or examples of business structuring for sharing ownership and income. The livestock

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share lease is probably the most used model, yet one that is passed over by consultants and producers as they attempt to solve personnel problems or locate competent labor services. Through historical development, legal precedent, and business practice, the share lease arrangement combines two separate legal entities, the landlord and the tenant, in the business of jointly producing hogs. Legal precedent has carefully kept the two legal entities separate, yet they are involved in joint ownership of selected property items; they share several input resources, including feed and supplies; and each party shares in the product or income.

Some frequently mentioned attributes of desirable employee incentive plans are (1) rewards (cash salary and fringe benefits) in proportion to contributions of his resources, usually labor, and management services; (2) a share in profits in proportion to equity ownership and to the risks assumed; and (3) participation in growth and success of the business over time. The livestock share lease provides all of the above attributes, especially if the lease is revised as technology changes and the value of the resources provided separately by the landlord (buildings) and the tenant (labor and management) are changed over time to reflect current market conditions.

We do not suggest that the livestock share lease is the structuring to adopt; but more attention might be given to this option as a particular hog unit expands over time, especially if continuity of labor and management services is desired.

The partnership. The regular partnership has potential application, especially for a father and son. Other than income splitting with a second individual tax payer, it provides no sheltering of income taxes and, for nonrelated persons, the shared liability problem is viewed as a potential pitfall. Its advantages are that it is easily formed, simple to dissolve, and flexible in the way it is capitalized; and with the conduit feature for reporting taxable income, it provides the full incentives of (1) profit sharing and (2) rewards for partial ownership by junior partners.

Like the share lease arrangement, the partnership is widely used in Illinois. The 1974 Census of Agriculture counted 13 percent of all farms organized as partnerships. However, our past experience with existing business structures shows that the typical partnership too often just "grew up" without careful planning; it frequently does not have a carefully written contractual agreement; and the accounting system is usually inadequate to document ownership shares of each partner unless the partners have equal ownership of capital and divide income equally.

The corporation. The basic legal attributes of all farming corporations are similar but the share holders have the option of "being taxed like a partnership" (the S chapter election) or being taxed as a separate entity (the C chapter election). This choice should be carefully evaluated. Although employee fringe benefit (using pre-tax dollars to purchase health and life insurance, housing, and similar "business" benefits) are available to both the C and S corporations, only the C corporation provides for sheltering of income from taxes by splitting taxable income between the corporation and the owners of the corporation. In the typical family corporation, where the shareholders are also key employees, this means splitting taxable income of one person between two tax-paying entities and, under the 1979 tax regulations, provides a sizable tax shelter for net income classified as "ordinary income."

Revenue or income that qualifies for capital gains treatment remains within the C corporation and the entire amount of net gains is taxed at the lower of the

corporate tax bracket or the 30 percent rate, whichever is lower. The 30 percent rate for corporate capital gains is equivalent to a 75 percent tax bracket for the proprietorship, when 60 percent of the capital gains are excluded and the remaining 40 percent is taxed at the highest cumulative tax bracket. This tax provision leads to the widespread practice of leasing the hog breeding herd to the operating corporation that farrows and finishes the market hogs, thus removing from the corporation the capital gains from the sale of raised breeding stock.

INCLUDING EMPLOYEES IN THE BUSINESS

The above review of legal entities and their application to farming units is very brief but should serve to highlight the major differences among them. We turn now to the specific assignment of how to involve employees in the various business structures.

Let us also assume that the employee is motivated by (1) cash salary; (2) fringe benefits that are essential needs (housing, food, medical coverage); (3) fringe benefits that are nonessential but desirable (life insurance, recreational opportunities); (4) rewards for above average or superior performance (profit sharing); and (5) partial ownership of the assets of the business, including the opportunity to share in entrepreneurial returns to his investment. Also let us assume the (a) proprietorship, (b) regular partnership, (c) S corporation, and (d) the C corporation as the choices of business structures.

The above two-way classification results in the following matrix and will be used to compare rewards among the different business structures:

Rewards	Prop.	Part.	S. Corp.	C. Corp.
1. Cash salary				
2. Essential fringes				
3. Non-essential fringes				
4. Profit sharing				
5. Partial ownership				

Cash salary does not differ in accounting or business treatment among the four structures. Labor salaries are business expenses to the employer and taxable income to the employee. However, federal regulations as to Social Security taxes differ according to the business structure: Owners of a proprietorship and partners in a partnership are considered as self-employed, whereas the shareholder-employees of corporations are required to pay both employer and employee Social Security taxes on salaries, up to the frequently revised maximum salary level. There is also the risk that large salaries paid to shareholders by C corporations may be ruled excessive by IRS. If this happens, the corporation loses a business expense deduction and the excess salary is taxed a second time as a dividend distribution to the shareholder.

Essential fringe benefits to the proprietorship owner are acquired with after-tax dollars. If these same benefits are provided to partners by the partnership, the cash value of the fringe benefits are reportable as taxable income to the partners. The "necessary requirement for employment" rule applies to housing provided to non-partner employees of partnerships.

For corporations, tax regulations are much more lenient in the use of pre-tax rather than after-tax dollars to acquire essential fringe benefits. Corporations may use pre-tax dollars to pay medical expenses, provide farm business offices, and, under special circumstances, even provide the personal residence of the shareholder-employee. The tax sheltering value of the fringe benefits is proportional to the tax bracket of the business. That is, there are no savings if the corporation has a break-even or tax loss situation.

One concept that has economic benefit to employees is the procedure whereby a base salary level is determined, then the cash value of essential fringe benefits that meet the "necessary requirement for employment" test is deducted from the base salary. This procedure saves the employee the income tax bite on that portion of his gross salary used to acquire the essential fringe benefits which he would normally purchase with after-tax net income.

The nonessential fringe benefits are probably highly overrated as an economic factor but are effective as psychological motivators on a selective basis with individual employees and owners alike.

Air-conditioned cabs on tractors and combines, two-way radios that work with tape decks and receive FM stations, comfortable office space, and showers in production facilities can be provided by all of the business structures and usually qualify as business expenses. Other nonessential fringes such as life insurance, and retirement programs that go beyond the dollar limits of IRA or Keogh plans available to self-employed individuals, may be provided by corporations and the tax bite can be deferred until after retirement. These special fringe benefits are also available to the proprietorship or partnership but must be acquired with after-tax dollars or require the use of other forms of retirement tax sheltering. Other possible fringes are recreation facilities, club memberships, and combined business-vacation trips. Business deductions for these latter items require very careful scrutiny by your accountant and attorney.

Profit sharing provides a very significant motivation to both owners and employees of the entire range of business structures. The anticipation of sharing entrepreneurial rewards, or profits, is what makes business wheels go round. In a perfectly predictable business environment, there would be no entrepreneurial rewards or profits; hence the acceptance of risk and the ability to manage risk are factors in all forms of business structures.

If we focus on employees only, profit-sharing plans permit the employee to share in rewards, usually in proportion to the capital resources and labor-management services that he provides to the business venture. The key requirement in effective profit sharing is that the accounting unit that measures profits must coincide with the business activity to which the employee contributes his labor and management services. Other key requirements are that an accounting method be used that reflects economic profits, not cash basis taxable income, and that the accounting records be an open book to employees.

Incentives based on physical production such as pigs weaned or total hogs produced may measure physical production but do not necessarily reflect profits. Yet these kinds of incentives are useful when the employee does not work in all areas of the accounting profit center. The unrealized gains from asset appreciation, such as rising land values, should not be included with net profits unless the employee contributed to the original acquisition of these assets during his employment.

Partial ownership of equity in the business unit is a mixed bag. For proprietors and partners with equity capital in the business, partial ownership is an important motivator. Partnerships especially provide significant incentives if profits are shared (1) in proportion to both labor and management services and (2) in proportion to equity capital ownership. This latter point has strong merit for "growing" sons or sons-in-law into increasing ownership of father-son partnerships, when the long-run goal is to turn the business over to the second generation.

There is substantial difference of opinion on whether nonrelated employees are motivated by minority ownership of stock in a corporation. The S corporation, meets basically the same objective of equity ownership as the father-son partnership. However, the S chapter election eliminates any significant tax sheltering opportunities, except for the fringe benefit package. The economic worth of the fringe benefits is not great and is largely offset by the greater costs of accounting and legal service required for corporations and by the added Federal Social Security taxes and additional state income tax corporations in Illinois. Overall, the S chapter choice may be questionable, except when the long-run goal is to maintain the full business intact, but with divided ownership among several persons.

The C corporation is a paradox. When tax sheltering is a key objective, payment of dividends to stockholders is avoided to eliminate double taxation of dividends, once within the corporation and again to the shareholder. Minority stock ownership in a family corporation that pays no dividends results in little or no voice in corporate policy, and the stock must be sold back to the corporation to realize any economic worth to the minority stockholder. Thus it is an asset with dubious current economic worth to the nonrelated employee. He must cash in the stock to see any tangible economic return but liquidation counters the original reason why ownership was offered in the first place. An exception to this feature of stock ownership may exist if there is a potential for future majority stock control and full ownership by the nonrelated employee. However, in family corporations, this is an unlikely prospect.

If cashing in the stock is a recurring event, as employees move to new positions or go into the hog business on their own, the corporation regularly must come up with new capital sources to finance the buy-out of minority stock ownership. Also, clear prior agreement on how to value the stock is essential. If stock sale restrictions are contained in corporation by-laws, and outside buyers are either not interested or not allowed, market value of the stock is meaningless. Valuations based on equity per share should specify how assets are to be valued or appraised. If the business is profitable, a price/earnings ratio based on several years of performance might be considered, but we do not have a good basis to determine a reasonable price/earnings ratio for hog producing corporations.

SUMMARY

Where employees are involved in the business, and the extent of employee involvement goes beyond the employee-employer wage contract, the typical hog business has the opportunity to adapt an accounting entity or profit center to coincide with the employee's business activity. Major decisions on structuring the business should probably depend on broader goals such as estate planning, two-generation transfers of business control, and possibly the desire to keep the business intact at probate time. If tax sheltering is a major goal, the objectives of the senior owner and the minority owner-employee are sufficiently diverse to create potentially serious problems if partial ownership is used as an employee incentive.

In forming business structures, there are ways to handle diverse goals but it requires careful planning and a hard look at the longer run goals of the business. The flexibility of selecting accounting entities offers a wide range of opportunity for profit sharing schemes. Unfortunately, partial ownership schemes must coincide with a legal entity.

Using the Futures Market

CLAYTON YEUTTER

I welcome this fine opportunity to speak on the topic "Using the Futures Market." If you happen to have read "Economics of Futures Trading for Commercial and Personal Profit," by the University of Illinois's own Tom Hieronymous, you already have a good grasp of the subject. He is one of our foremost authorities on futures trading, he has assisted us in developing some of our contracts, and it is a pleasure to visit the great campus he represents. If you have not read his book, well that is why I am here today! It is a pleasure to be addressing such an august group, representing a state whose swine and pork products make a tremendous contribution to the economy and well-being of the United States.

We are all aware of the great progress this country has made over the years in agricultural productivity. We are literally the breadbasket of the world. Now we are reaching the stage where it is of supreme importance to be knowledgeable and efficient in marketing the bread from that basket! Through the development of modern farm machinery, a wide variety of fertilizers, hybrid seeds, and better livestock breeding programs, agriculture is no longer a labor-intensive business based on muscle and physical exertion; it is now a capital-intensive business requiring management and marketing skills.

In today's highly competitive world, it is the man who knows his options in the marketplace who is most likely to sleep in comfort. Agriculture, more than any other industry, must live with uncertainty.

It is this very uncertainty that created futures markets and the Chicago Mercantile Exchange. Were our markets not so volatile, there would be no economic rationale for futures markets. But they are volatile, and they will continue to be that way. Over the past ten years, and particularly since 1972, when the Soviet Union first entered our market on a large scale, the need for futures markets has been clearly demonstrated.

We did not really have a global market for agricultural commodities before 1972 because the Soviet Union, as a matter of policy, did not participate in it. Since then, however, the Soviets have been active participants, and they have been joined occasionally by the People's Republic of China. The periodic presence of these giants has contributed not only to the establishment of a global market, but also to its unpredictability. This has had - and will continue to have - major ramifications in the marketing of both grain and livestock here in the United States.

As you all know, the demand for agricultural products is characterized by price inelasticity. By this I mean that a small change in supply will result in a relatively large change in price. Therefore, when there is an important shift in demand for U.S. grain, such as a major Soviet or Chinese purchase (or, alternatively, an unexpectedly good crop in those or other major producing areas), there

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is a striking impact on prices. That sets up the perfect situation for futures markets to prove their economic value.

A futures market provides three basic economic functions: The first is its use as a price discovery mechanism, revealing to all the expected price of a commodity based on supply and demand factors perceived at a given point in time. The second is its usefulness as a disseminator of information - sending out price quotations and volume figures (which indicate the amount of buyer and seller interest there is in the various commodities) to the media, businesses, the brokerage community, and individuals throughout the world. The third function is one that affects so many of you in the livestock industry - the ability to shift price risks from your own shoulders to the shoulders of someone who is willing to bear that risk. It is through this risk transfer mechanism that livestock producers and processors are able to enhance their borrowing ability, and often their earnings as well.

I would now like to illustrate the value of a futures market to hog producers by giving you an example of what a July 1979 "hedge" would have accomplished. Bear in mind that market prices will vary in different parts of the country and costs will vary among hog producers. Therefore, the illustration may not fit your situation perfectly, but it should be a good approximation.

In March of this year, production costs for a hog producer would have been in the area of $43 a hundredweight, with July marketing in mind. During the first two-thirds of March, the producer could have hedged July hogs on the Chicago Mercantile Exchange in the $52 to $54 range before a price decline set in. So he could have locked in a profit in the area of $10 per hundredweight. The actual cash price at Peoria in July ranged between a low of $38 and a high of $43, which means that the unhedged producer lost money or, at best, broke even.

In the case I have cited, the producer probably would not have made actual delivery on his futures contract, but would have sold his hogs on the cash market. He could then have liquidated his futures position in the low 40s for a net gain of at least $10 per hundredweight.

This was a case in which the hedger made a substantial profit on his futures contract in the face of declining cash prices. I hasten to point out that these opportunities do not arise every day. Nor should the producer enter the futures market for the sole purpose of making a profit. The hedger's basic purpose in selling those futures contracts was to shift some of his risk, in essence to buy some price insurance for at least part of his operations.

In this example the cash price of hogs in March was in the $50 area, and if it had stayed there the producer would have made a profit without hedging. He would not have needed a futures market. But the price did not stay there, and his hedge made the difference between a loss and a good profit. Had he put on the same sell (short) hedge and prices had risen, he would have made a gain in the cash market about equal to his loss in the futures market - and still would have locked in a satisfactory profit.

Let's apply the same figures to the meat packer, the next stage of this marketing chain. He would have put on a long hedge in March, that is, he would have bought futures in March against a projected cash purchase of hogs in July. The results, of course, would have been just the opposite of those experienced by the hog producer. The producer lost money on his hogs, but made a profit on his

futures contract; the packer lost money on his futures contracts, but bought hogs in the cash market at an attractive price. The point is: both the producer and the packer obtained price protection through the use of futures contracts.

A simple rule of thumb is to sell in the futures market when you have a product you are going to sell later in the cash market. Buy in the futures market when you are going to buy a product at some future date. But do not do so automatically. Hedge only when it makes good economic sense to do so.

I cannot give you a one-day seminar in the time alloted today, but let me review a few key elements of a successful hedging program. One is the vital need to know your costs, as any good businessman will. That means ALL costs, of course. Without that knowledge, there is no way to know when to put on a hedge - that is, when you can lock in a satisfactory level of profit on an attractive input cost.

Another important element is to know our contract specifications. Since these change from time to time, ask your commodity broker to keep you up to date.

You must also know your "basis," the difference between the price quotes on our boards and the cash price available to you at the time your hogs are marketed. This difference reflects transportation costs primarily, but other factors are involved too. If your basis estimate is accurate, you will have a perfect price-protecting hedge. If, however, your estimate is off target, you will have either a loss or gain from your expected results.

Basis, of course, tends to narrow toward zero as the delivery month of a futures contract approaches. It is this convergence of cash and futures prices during the delivery month that protects the hedge. Without such convergence, a futures market would not work properly. Fortunately, basis patterns between established markets tend to repeat themselves. Therefore, there is a degree of reassurance that what is happening tody correlates with what happened in the past. Just remember, the producer who does not know where he stands on basis will be hedging partially blindfolded, and that can be hazardous.

Finally, for hedging to be successful, you must have a solid business relationship with two people: your banker and your broker. The former must understand your hedging strategy, and must be FULLY committed to meeting your margin calls. With this kind of understanding, a lot of credit woes will disappear. Margin is, of course, the earnest money you must put up to guarantee fulfillment of your contracts. If the market moves against you, you will receive a call to bring this sum up to its required level.

The commodity broker is no less important than the banker. He is your direct link to our trading floor. A broker who cannot (or will not) earnestly try to understand your needs, know your operation, and attempt to help achieve your marketing goals is not a good choice to handle your futures business.

With a good broker, one who has had experience in futures and knows how to set up a hedging strategy, and a good banker, you can become an accomplished hedger with relative ease.

You should not expect that every time you sell futures the price will plunge and you will make a big profit on your futures contracts. Sometimes you will be

on the wrong side of a price movement. But, if you have locked in a healthy profit, missing out on an even larger profit is not all that bad! After all, that futures contract gives you a good guarantee that you will not have a smaller profit - or a loss.

We do not know how much of our livestock production in the United States is hedged. We do know from our experience on the Chicago Mercantile Exchange that the volume is expanding rapidly. In the next 10 to 20 years, it is safe to predict that the growth of the futures industry will dwarf anything we have seen so far, assuming our free markets are not impeded by price controls or some other sort of government interference.

Like most futures contracts, futures on live hogs took a few years to mature after their 1966 introduction. By 1970, trading volume was over 100,000 contracts (on an annual basis); by 1973 it surpassed the million mark; and last year it rose to an all-time record of nearly 1.8 million. That is solid expansion!

Another key indicator of the market's vitality is measured by what we call open interest. That figure is the number of futures contracts that are unliquidated or "open" at a given point in time. Our Exchange has experienced a steady climb in this meaningful statistic. What this means is that our markets have good liquidity, that users can get in and out when they wish. This is an extremely important factor to hedger and speculator alike.

Of course, no one can guarantee to a hog producer (or any other producer, for that matter) the attractive kind of hedge I have described today. If it is not there, they should not hedge! But it is also foolhardy for producers to miss the opportunity to lock in profits on at least some of their animals - when a good hedge is there. If they do not now know how to hedge, it behooves them to learn!

The Chicago Mercantile Exchange has many aids to help people comprehend how to put this management tool to work. We have dozens of pamphlets and brochures, and public relations and marketing people at hand to explain futures. It so happens, too, that we will be conducting a series of Farm Forum programs in Illinois next February. These consist of one-day seminars on hedging, conducted in cooperation with the University of Illinois Cooperative Extension Service. In addition to our staff experts and a film on hedging, you will hear from a University of Illinois authority, one or more ag lenders, and livestock producers who have hedged. There will be a workshop in which you will track futures prices and decide when to put on a hypothetical hedge.

Here are the counties we will be visiting: Shelby on February 5; Peoria on February 6; Pike on February 7; Knox on February 12; Bureau on February 13; and Whiteside on February 14. More specific information will be available later from the county agents in each of these counties.

All of us must begin to think of hedging as buying price insurance. A futures market is the only public forum in which this can be done. Forward contracting may be an alternative, but it does not have nearly the flexibility of a hedge. Hedging really does work for hog producers (and packers). If you hedge, you will sleep a lot more comfortably at night! And so will your bankers!

ROBERT A. [illegible]
[illegible] MUMFORD [illegible]
UNIVERSITY OF ILL[illegible]
URBANA, IL [illegible]

University of Illinois

PORK INDUSTRY CONFERENCE

December 3-4, 1980
College of Agriculture
Department of Animal Science
Cooperative Extension Service
Agricultural Experiment Station
University of Illinois at Urbana-Champaign

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WELCOME TO THE PORK INDUSTRY CONFERENCE! It is a pleasure to have you attend.

Commercial swine production has become industrialized. It is now a business in which experts in animal production, more than ever, must be concerned about finance, personnel management, labor efficiency, quality control, industry image, government regulation, etc. In other words, it is big business which requires constant awareness of advancements in technology, changes in organizational management and government policies and changes in the factors of production. Only those who make an effort to be informed in all facets of the business will be likely to operate profitably.

This conference is designed to assist swine producers to stay abreast of developments vital to their business. We hope that it will be recognized as and become a part of a continuing education program for professional, large-scale swine producers.

You are here because you need and value information to apply to your business. We hope to provide it.

We will be interested in your suggestions to make future conferences of maximum benefit to you.

D. E. Becker, Head
Department of Animal Science

The Department of Animal Science at the University of Illinois

THE DEPARTMENT OF ANIMAL SCIENCE IS CONCERNED WITH THE MULTIDISCIPLINARY ACTIVITIES associated with the production, care, and utilization of animals useful to mankind. It includes primary fields of study in behavior, genetics, environmental physiology and management, meat science and muscle biology, nutrition, and reproductive physiology. Beef cattle, horses, poultry, sheep, swine, and various companion and laboratory animals are studied to assist animal producers and owners to obtain more efficient performance, more economical production and other such improvements which ultimately benefit the general public.

Our staff includes about 140 people of whom 50 are academic staff members; 40 are nonacademic staff members in the offices, research farms, and laboratories; and about 50 are part-time teaching or research assistants who are pursuing graduate study. Several of the senior academic staff members have received national and international recognition for their accomplishments.

The work of the Department is divided into extension, research, and teaching. Extension or off-campus teaching is handled by eight full-time staff members. Each extension specialist conducts seminars, clinics, field days, etc., for livestock or poultry producers. Their primary work is to apply new research findings to the business of animal production or product processing.

Over the years the Department has had very active and productive research programs. Some of the more notable research accomplishments include the discovery of the value of antibiotics in livestock feeding, the elucidation of the amino acid needs of swine and poultry, the utilization of inorganic nitrogen by ruminants, the development of simplified corn-soybean meal rations for swine feeding, and the development of confinement production technics, particularly the use of slatted floors. Current research studies pertain to such topics as recycling of animal wastes, decreasing prenatal mortality in gestation sows, the inheritance of blood groups in swine, and maximizing the utilization of corn stalks by brood cows.

With the recent increase in student numbers, the teaching load in Animal Science increased significantly. At present our Department provides instruction for about 2,800 students a year in the classroom, and staff members advise 460 undergraduate (mostly juniors and seniors) and 98 graduate majors. Our graduates have many opportunities for employment.

The future of the Department of Animal Science appears bright. Meat consumption and the use of animals for companionship and in recreational activities are at all-time highs and seem likely to increase further. Such an expanding animal industry will require an educational program to produce well-trained animal scientists and research programs geared to produce new and improved technology.

University of Illinois
PORK INDUSTRY CONFERENCE
December 3-4, 1980
Ramada Inn, Champaign

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Nutrition of the Peripartal Sow

GARY L. CROMWELL

The peripartal period, or the period just prior to and subsequent to parturition, is one of the most critical periods in the life cycle of swine. A sound nutrition program during the peripartal period is necessary in order to best prepare the sow for parturition and to insure adequate production of colostrum and milk for the newborn pigs.

Two characteristics of the litter at birth that bear economical importance are (1) the number of live pigs in the litter and (2) the average birth weight of the pigs. Obviously, a sow must farrow a large litter of live pigs if she is to wean a large litter. Equally as important as litter size is the birth weight of the pigs, because of the relationship of birth weight to the survivability of suckling pigs. The data of table 1 illustrate that the larger the pig is at birth, the greater are its chances of survival from birth to weaning. In addition, heavier pigs at birth tend to be heavier at weaning.

Litter size is established early in gestation, and there is very little that can be done from a nutrition standpoint after implantation has occurred (at 16-18 days postbreeding) that will influence the number of pigs born. The sow possesses the ability of protecting her developing litter by drawing from her own body reserves during periods of nutrient insufficiencies. For example, the ability of the sow to buffer her developing fetuses against a severe protein deficiency is illustrated in a series of studies conducted in the mid 1970's at Kentucky. Gilts fed a 2% protein diet from 20 days postbreeding to parturition farrowed nearly as many pigs per litter as gilts fed a protein-adequate (17%) diet (table 2). Similarly, Baker and coworkers at Illinois fed very low levels of energy to gilts during gestation and found that litter size was not affected, although birth weight and weaning weights were significantly reduced (table 3). These data suggest that prepartum nutrition of the sow has little influence on litter size.

Unlike litter size, individual birth weight of pigs has been shown to be influenced by the amount of feed the sow is fed during gestation. Although the design of many experiments is such that one cannot separate the effects of protein level from energy level, it appears that the energy level fed to the sow has a greater effect on pig birth weight than does protein level. For example, a severe protein restriction during gestation had very little effect on pig birth weights (table 2).

Henry and Etienne summarized the results of a large number of experiments and concluded that birth weight of pigs increased in gilt litters by .03 pound and in sow litters by .08 pound for each additional 1,000 kcal of digestible energy (DE) fed daily to the sow during gestation, over the range of 3,000 to

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12.000 kcal of DE per day (figure 1). Assuming that a corn-soybean meal diet contains about 1,500 kcal of DE per pound, their summary indicates that one could expect an increase in birth weight of .05 pound per pig in gilt litters and .12 pound per pig in sow litters for each additional pound of diet fed daily during gestation (table 4). They also found that gestation weight gain of both sows and gilts increased by 28 pounds for each additional pound of gestation feed fed daily.

The early studies of British workers (Elsley *et al.*) demonstrated that approximately one-half of the fetal growth occurs during the last three to four weeks of gestation (figure 2). Therefore it would seem that a reduced feeding level during early gestation followed by an increased feeding level during late gestation would be a more efficient means of providing nutrients to the sow than feeding a constant level throughout gestation. Indeed, some producers follow this type of feeding program, increasing the feeding level during the last month of gestation.

We recently conducted an experiment to evaluate a low feeding level during early gestation (3.2 pounds/day in summer, 4 pounds/day in winter) followed by a stepped-up feeding level from day 90 to day 113 of gestation (7.2 pounds/day in summer, 9 pounds/day in winter). Control gilts received the same amount of total gestation feed, but it was fed at a constant level throughout gestation (4 pounds /day in summer, 5 pounds/day in winter). Similar gestation weight gains, litter size and pig birth weights occurred for the two feeding regimens (table 5). Although weight gains were less for the variable-fed group during the initial 90 days of pregnancy, they simply gained at a sufficiently faster rate after day 90 that their farrowing weight was about the same as sows fed the constant level throughout gestation.

These data indicated that an increased feeding level during the last three weeks of gestation is no better than feeding a constant level throughout gestation, as long as the total gestation feeding level is the same. On the other hand, if sows or gilts are a bit thin toward the end of gestation, increasing the sow's feed intake during the last few weeks of gestation will increase her body energy reserves for lactation and should result in slightly heavier pig birth weights.

With respect to nutrient levels, the NRC (1979) suggests a protein level of 216 grams/day during gestation. At a feeding level of 4 pounds of a corn-soy diet per day, a 12% protein level will meet the requirement for lysine (.43% or 7.7 grams per day) as well as the other amino acids. Although the metabolic requirement for amino acids is greater during the latter phases of pregnancy, the lack of any response to an increased feeding level (hence, increased protein intake) during late gestation suggests that the sow utilizes the dietary amino acids more efficiently as pregnancy progresses.

During the mid 1970's many studies were conducted to evaluate supplemental fat in the diet of the sow during late gestation and early lactation. This flurry of research activity resulted from reports from the University of Georgia (Seerley *et al.*) that baby pig survival, particularly survival of small pigs, was increased when fat was included in the diet from day 109 of gestation to parturition.

This area of research was recently summarized in reviews by Pettigrew (1979) and Moser and Lewis (1980). As one might expect, fat improved reproductive performance in some experiments, but was of no value in others. However,

averaged across all experiments, there was a slight improvement in litter size and average weight of the pigs at weaning and an improvement in survival rate as a result of adding fat to the sow diet (table 6).

Pettigrew concluded that the magnitude of improvement in the survival rate of pigs attributable to fat supplementation of the sow's diet was dependent on several factors. The response was greatest when fat was included in the sow's diet prior to parturition, and a high level of fat was required (2 to 4 pounds per sow) to maximize the response to fat. In addition, the response was greatest in herds having a low survival rate (less than 80%) of pigs from birth to weaning (table 6).

The newborn pig is born with very limited energy reserves. It has very little carcass fat (3% or less) and limited glycogen stores, which are rapidly metabolized during the first 18-24 hours of life. Because of the lack of subcutaneous fat for insulation, a sparce hair coat and a poorly developed thermoregulatory system, the newborn is very susceptible to chilling unless it receives an ample supply of colostrum soon after birth.

The improved pig survival resulting from fat additions to sow diets is thought to be due to (1) a slight increase in the fat reserves in the newborn pig and (2) an increase in the fat content of the sow's colostrum and milk. In addition, a few studies indicate that total milk production may be increased in sows fed fat-supplemented diets. The increased fat (energy) reserves and increased energy concentration in the milk apparently allows the smaller, weaker pig a better chance for obtaining sufficient energy supplies early in life.

Two common feeding practices that have been extensively used in the swine industry for years are (1) the feeding of a bulky, laxative-type diet around farrowing time and for the first few weeks of lactation and (2) the practice of not feeding on the day of parturition followed by a gradual increase in the feeding level until the sow is on full feed at 7-10 days after farrowing.

Although these feeding practices appear sound, there are very little, if any, research data to support their use. Table 7 summarizes five experiments in which wheat bran, alfalfa meal, beet pulp or a chemical laxative was fed prior to farrowing and during early lactation. No benefit in pig performance occurred in these experiments from the use of a laxative-type diet.

Nevertheless, we continue to hear of constipation problems in sows at or shortly after farrowing, and agalactia appears to be more prevalent when sows are constipated. Fiberous feedstuffs at levels of 5-15% of the diet or chemical laxatives, such as potassium chloride or magnesium sulfate (Epsom salts), have been shown to be effective in softening the feces of sows. An additional advantage for chemical laxatives is that they do not dilute the energy content of the lactation diet, since they are quite effective at low dietary levels (.75-1%).

In a recent test at our station we encountered no lactational problems when sows were full-fed from a self-feeder immediately after farrowing as compared with sows that were gradually increased to full-feed. Pig survival and weaning weights were similar for both feeding practices (table 8).

The daily requirements of the sow are about three times greater during lactation compared with gestation because of the high nutrient demands for milk production. On a percentage basis, however, the requirements for lactation

are not greatly different than the requirements for pregnancy because the feeding level is considerably higher. The NRC (1979) suggests a protein level of 13% and a lysine level of .58% which are slightly higher than the 12% protein and .43% lysine levels suggested for gestation. Self-feeding during lactation is a labor-efficient means of meeting the nutrient requirements of the sow. Scale feeding according to the number of pigs in the litter is as effective as self-feeding, but requires more labor.

A modest reduction in feed allowance is of little consequence provided that the protein, calcium, phosphorus and other nutrient levels in the diet are high enough to meet the daily needs to the sow. The sow is quite efficient in drawing from her fat reserves to meet the energy requirements for milk production, however, drawing from body protein reserves to meet the demands for milk protein production is not an efficient process. Excessive weight loss during lactation, particularly in sows carrying low fat reserves at farrowing, should be avoided as it can have a detrimental effect on subsequent reproduction.

A high level of antibiotics in the peripartal diet is generally considered to be beneficial. There is some evidence that antibiotics in the sow feed reduces the incidence of agalactia and uterine infections that sometimes occur shortly after farrowing. The data of table 9 suggests that pig survival was increased slightly and weaning weights were increased by about 5% when antibiotics were included in the peripartal diet.

The greatest and most consistent benefit from antibiotics in the sow herd is in the breeding ration. For example, feeding a high level of antibiotics from weaning to rebreeding (for an average of 8.6 days) resulted in a 9% improvement in farrowing rate and a 0.2 pig improvement in litter size at the subsequent farrowing (table 10).

Table 1. Relation of birth weight on survival from birth to weaning and on subsequent growth rate

Weight Range, lb	No. Pigs	Birth Weight, lb	Survival to 56 days, %	56-Day Weight, lb	154-Day Weight, lb
Less than 1.4	51	1.17	5.8	21.3	127.0
1.4-1.99	264	1.72	36.0	27.3	158.3
2.0-2.59	756	2.29	59.1	30.7	173.0
2.6-3.19	1418	2.80	73.6	34.2	182.0
3.2-3.79	831	3.41	82.4	36.8	189.2
3.8 and more	361	4.10	87.5	38.2	196.0

Adapted from Noland and Johnson, 1972.

Table 2. Effects of protein deficiency on reproduction

Protein, %[a]	2	17
No. gilts	58	54
Gestation gain, lb	8	55
Litter size		
Total pigs	9.2	9.6
Live pigs	8.1	8.8
Avg. birth weight, lb	2.5	2.6

[a]4 pounds daily fed to gilts.
DeGeeter *et al.*, 1972, and Hammell *et al.*, 1976.

Table 3. Gestation feeding levels for gilts[a]

Gestation feed, lb/day:[b]	2.0	3.1	4.2	5.3	6.6
Gestation weight gain, lb	13	67	113	138	164
Pigs born alive	7.6	7.9	8.2	8.7	8.0
Pigs weaned	6.0	5.7	6.3	6.7	6.1
Avg birth weight, lb	2.2	2.5	2.7	2.7	2.7
Avg 21-day weight, lb	9.3	10.5	11.1	11.9	11.8

[a]62 gilts/treatment, Baker *et al.*, 1969.
[b]Diet formulated to meet the daily nutrient requirements when fed at 4.2 lb/day.

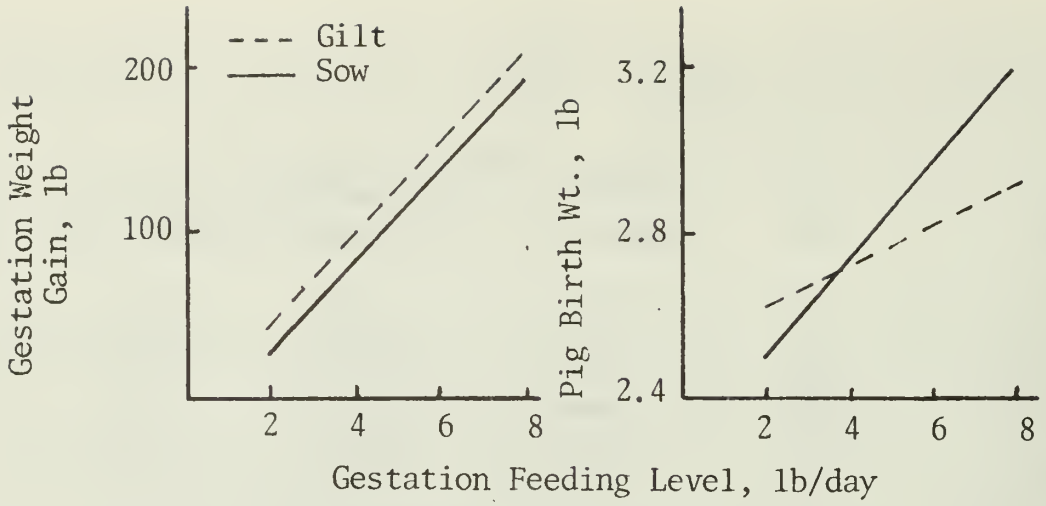

Figure 1. Effects of gestation feeding level on weight gain of sows and gilts and on birth weight of their pigs. Summary of 29 experiments involving over 5,000 litters. (Adapted from Henry and Etienne, 1978.)

Table 4. Effect of gestation feeding level on pregnancy weight gain and pig birth weight

Feeding Level lb/day	Dig. Energy Kcal/day	Gestation gain, lb		Avg pig birth weight, lb	
		Gilt	Sow	Gilt	Sow
2	3,000	45	23	2.61	2.47
3	4,500	73	50	2.66	2.60
4	6,000	101	78	2.71	2.72
5	7,500	129	106	2.76	2.84
6	9,000	157	133	2.81	2.96
Change/lb of feed		28	28	0.05	0.12

Based on 28 experiments involving over 5,000 litters.
Adapted from Henry and Etienne, 1978.

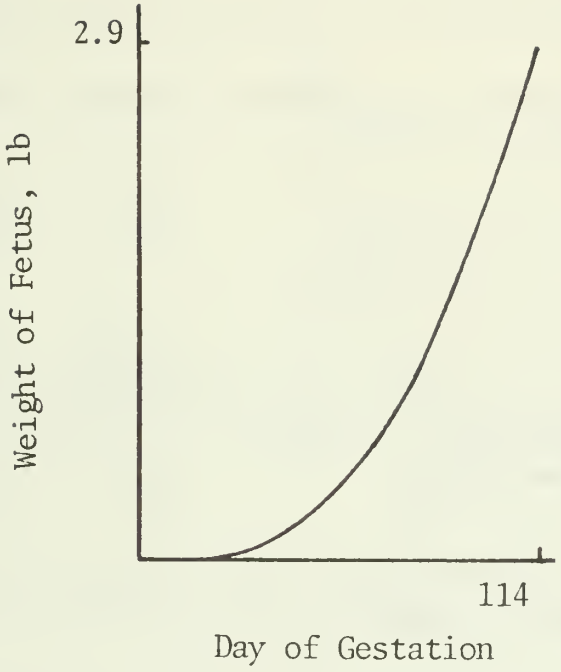

Figure 2. Growth of the pig fetus during the gestation period.

Table 5. Constant vs variable gestation feeding pattern[a]

	Daily feed, lb[b]	
Breeding to day 90:	5	4
Day 90 to farrowing:	5	9
Sow daily gain, lb		
Breeding to day 90	0.58	0.37
Day 90 to farrowing	1.04	2.08
Total gestation gain, lb	77	81
Pigs born alive	9.2	9.2
Avg birth weight, lb	2.93	2.97

[a]111 litters, Cromwell *et al.*, 1980.
[b]These levels were fed in the winter. In the summer, feeding levels were 4 vs 3.2-7.2 lb/day.

Table 6. Supplemental fat in the peripartal diet for sows[a]

	No. litters	Control	Fat[b]	Improvement
Litter size	677			
Pigs born alive		10.0	9.9	---
Pigs weaned		8.1	8.4	0.3
Avg pig weight	356			
Birth, lb		3.10	3.06	---
21 days, lb		12.25	12.45	0.20
Survival, birth to weaning, %	339			
Herds with poor survival (<80%)		75.9	80.0	4.1
Herds with good survival (>80%)		88.1	88.7	0.6

[a]Adapted from summaries by Pettigrew, 1979, and Moser and Lewis, 1980.
[b]Ranged from 4 to 20% of the diet.

Table 7. Laxative diets for peripartal sows[a]

	Corn-Soy	+Laxative[b]
Pigs born alive	9.62	9.59
Pigs weaned	7.99	7.98
Survival, %	83.1	83.2
Weaning weight, lb	11.14	10.99

[a]Summary of 5 experiments, 612 litters.
[b]5-15% wheat bran, 5-15% alfalfa meal, 5% beet pulp or .75% KCl fed 3-7 days prior to farrowing and for 2-4 weeks of lactation.

Table 8. Restricted vs full-feeding of sows for the first week after farrowing

	Restricted[a]	Ad Libitum
No. sows	39	37
No. pigs born	9.6	9.6
At 3 weeks		
No. pigs	7.5	7.7
Avg weight, lb	12.2	11.6
Survival, %	79.2	81.4

[a]Fed 0, 2, 4, 6, 8, 10, 12 lb/day for days 1-7 after farrowing. Stahly *et al.*, 1976.

Table 9. Antimicrobial agents in the peripartal diet for sows[a]

	Control	Antimicrobial[b]
Pigs born alive	8.96	9.13
Pigs weaned	8.01	8.25
Survival, %	89.4	90.4
Weaning weight, lb	8.77	9.20

[a]Summary of 7 experiments, 787 litters.
[b]Tetracyclines, ASP-250, tylosin or copper sulfate fed from 3-5 days prepartum through 7 to 21 days of lactation.

Table 10. Antibiotics for sows from weaning to breeding[a]

	Control	Antibiotic[b]
Conception rate, %	68	76
Farrowing rate, %	61	70
Live pigs/litter	9.8	10.0

[a]182 sows, Krug *et al.*, 1978.
[b]1 g/day of the antibiotic-sulfa combination, Aureo SP-250, from weaning to 3 days postbreeding, an average of 8.6 days.

Maximizing Sow Productivity

HENNING E. NIELSEN

No single factor is so important for the productivity of a sow herd as the number of pigs produced per sow per year. Figure 1 shows results from an economic survey of herds with different rising numbers of pigs raised per sow per year (Aagaard & Studstrup 1977).

It is clearly shown that the gross return rises with increasing number of pigs per sow per year. The variable costs which cover feed are only slightly affected by the number of pigs per sow per year and therefore the difference between gross return and variable cost - the gross margin - is influenced rather strongly. Thus the return to cover the fixed cost is greatly influenced by litter size.

The survey was carried out in Denmark, and prices of pigs will of course vary between countries, as will cost of feed and buildings, but the trend shown in Figure 1 is universal, as the number of sows needed for producing a certain number of pigs will be reduced as number of weaners are increased.

Table 1 shows the influence of number of sows needed to produce 1000 pigs with increased productivity.

Table 1. Number of sows to produce 1000 pigs per year

No. of weaned pigs/sow/year	12	16	20	24
No. of sows needed	83	62	50	42

FACTORS INFLUENCING SOW PRODUCTIVITY

Number of piglets per sow per year are influenced by the farrowing interval and litter size. Figure 2 shows the various factors influencing the productivity of a sow.

Number of pigs per sow per year can be increased by reducing the interval between farrowing and conception. This can be done by reducing the lactation length and the period between weaning and conception, whereas very little can be done to alter gestation length as it is almost constant.

Litter size can be enlarged by increasing ovulation and conception rate or by reducing losses in the pre and postnatal periods.

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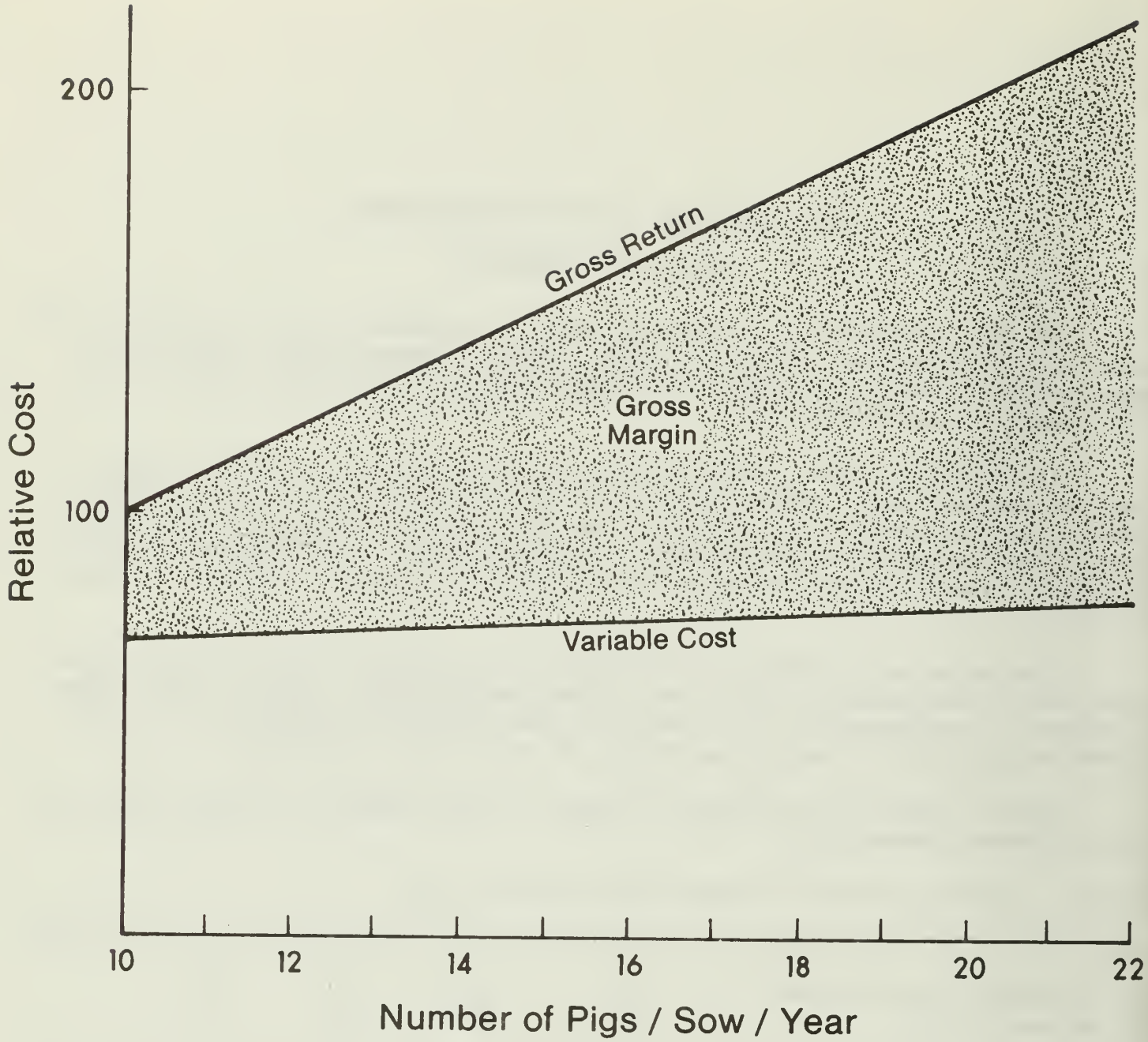

Figure 1. Economic results with increased number of pigs per sow per year.

The overall efficiency of a sow herd will also be influenced by age of gilts at conception, weight gain of sows, culling rate and procedure, boar policy and feed cost.

PERIOD BETWEEN WEANING AND CONCEPTION

In many sow herds anestrus is a great problem. It appears all the year round but it is worse during late summer and at the beginning of the fall. It is often called summer infertility, but the cause is not strictly heat. Tomes & Nielsen (1979) compared reproductive performance in Australia and Denmark and found that anestrus and low conception rate occurred in both countries during summer but there is a great difference in climate, as the main temperature is about 10°C higher in Australia than in Denmark, and the summer temperature in Denmark is below the average yearly temperature in Australia. (Figure 3) Several factors may be responsible for lack of normal estrus in sows, but the presence of boars have a marked stimulating effect on breeding activity in sows (Hughes & Cole 1976). In housing it is therefore a good idea to arrange for newly weaned sows and gilts approaching maturity to be subject to maximum boar influence (English *et al.* 1977). Newly weaned sows and gilts reaching maturity should be housed adjacent to boars thus providing for the necessary stimulus for prompt heat. Appropriate housing facility for sows and gilts at the period of mating is undoubtedly the most important means of controlling estrus in sow herds.

GESTATION PERIOD

The average gestation period in swine is 114 days, however, at normal gestation period it can vary from 110-118 days. A negative correlation is found between gestation length and litter size. However, nothing can be done under practical conditions to alter gestation length in order to improve sow productivity.

LACTATION PERIOD

An efficient method to increase numbers of pigs per sow per year is to shorten the lactation period. In theory, numbers of litters per sow per year may be increased by 0.1 by shortening the lactation period by 1 week. The assumption for this is that the period between weaning and estrus and the conception rate is unaffected by weaning age. This is, however, not true. If the lactation period is very short, the sows will be inconsistent as far as post-weaning estrus is concerned (Danielsen 1980, Allrich *et al.* 1980). Conception rate will also be lower, if the sow is mated shortly post farrowing (Varley & Cole 1976). However, the greatest effect of very early weaning on reproductive performance is a negative influence upon litter size (Varley & Cole 1976, te Brake 1978). Based on recent experiments (Danielsen 1980) weaning before 4 weeks of age cannot be recommended. Weaning earlier than 4 weeks may give more litters per sow per year, but as the litter size will be smaller, total numbers of pigs produced per year will also decline. Table 2 shows the effect on the annual output of sows of shortening the lactation period.

OVULATION

Increased energy intake for gilts 10-14 days before mating proved to result in an increase in the number of eggs shed (Zimmerman *et al.* 1960). Some producers practice starvation of the sows on the day of weaning the piglets. The idea is to get a better drying off of the sows. However, starvation for 24 hours

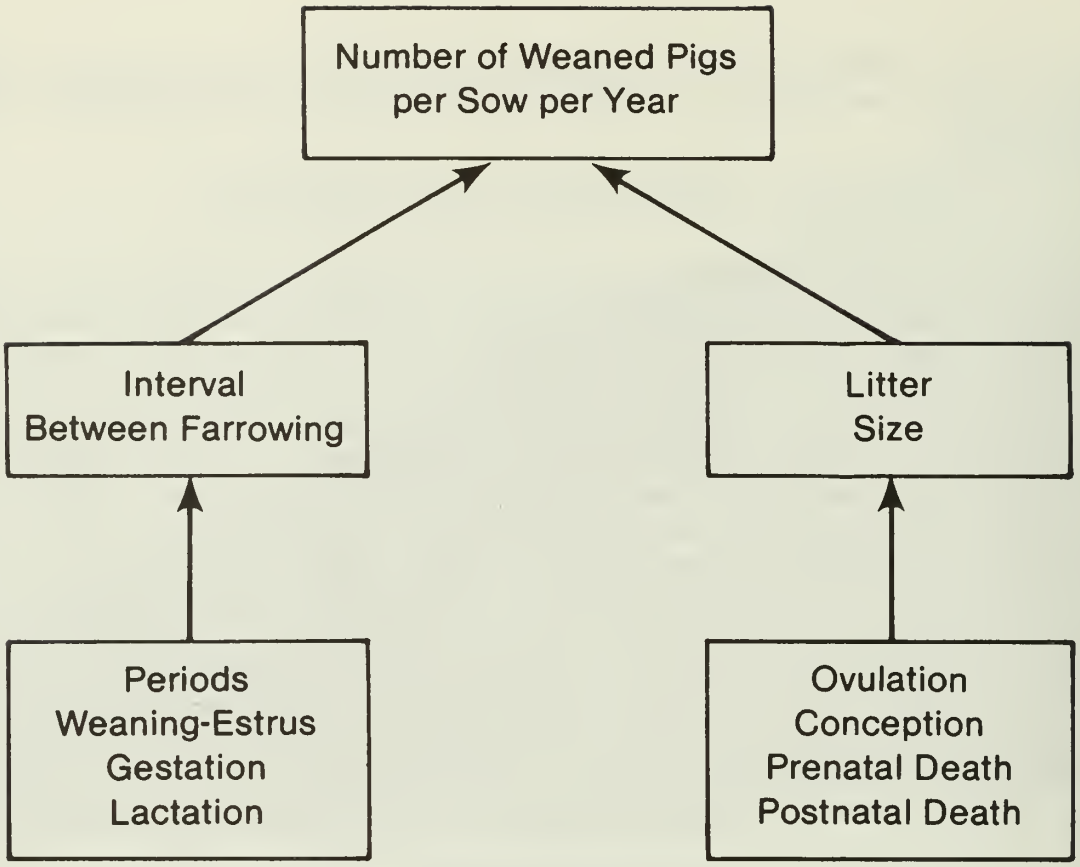

Figure 2. Factors influencing number of pigs per sow per year.

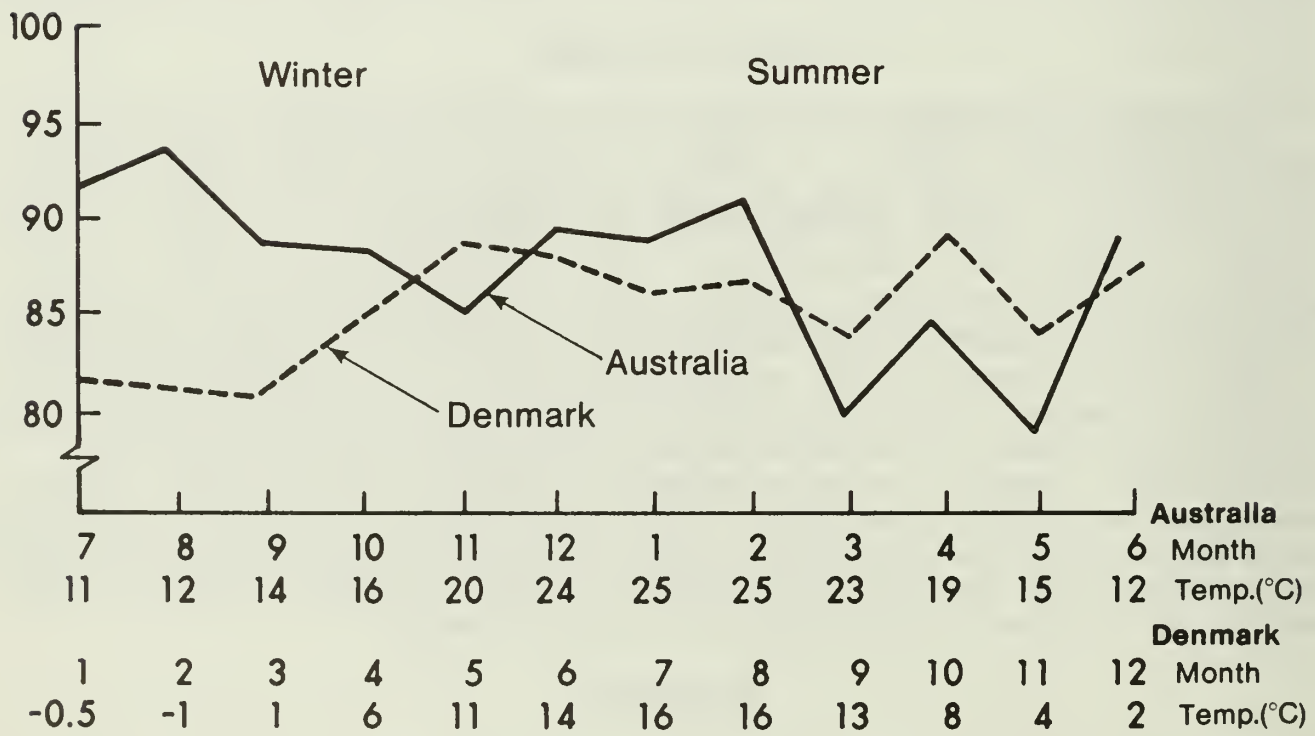

Figure 3. Variation in conception rates in Australia and Denmark related to months and average outdoor temperature.

Table 2. Increase in number of pigs produced per sow per year by reducing the lactation period from 8 to 2 weeks

Weaning age in weeks	Additional no. of pigs per sow on an annual basis
8	---
7	0.6 - 0.8
6	1.2 - 1.4
5	1.8 - 2.0
4	2.2 - 2.5
3	1.8 - 2.5
2	1.6 - 2.3

post weaning can have an adverse effect on the period from weaning to estrus, and it can also have a negative influence upon conception rate (Shearer & Adam, 1973). It is recommended to feed sows quite heavily during the first week after weaning.

The ovulation rate is higher for sows than for gilts. For gilts the rate increases from first to second heat and from second to third heat. Gilts mated at first, second and third estrus produced, respectively, 7.8, 9.8 and 10.2 piglets in the first parity (MacPherson *et al.* 1977).

CONCEPTION

Under normal conditions, nearly all eggs shed are fertilized at mating. However, if the sow or gilt is mated too early or too late, the chance of conception will be reduced. Also, if the sow conceives after early and late mating in the estrus cycle the chance of fertilizing all eggs is reduced (Polge 1975).

The conception rate will depend on the health of the sow, the fertility of the boar, and also on the general health of the boars.

PRENATAL DEATH

As regards prenatal death, the greatest losses take place early in gestation, primarily during the first 3 weeks after mating (Hansen *et al.* 1976). In some cases, especially in large herds, losses during the latter part of pregnancy may also be a great problem. It is then often connected with infection by SMEDI- and Parvo-viruses (Muirhead 1976).

An effective method of increasing numbers of pigs per sow is to use crossbreeding. The improvement in litter size by applying crossbreeding depends very much on the breeds used as well as on the breeding program. The reason for cross-bred pigs producing larger litters than purebred pigs is probably because of a lower prenatal death rate during the first period of gestation (Jensen 1975).

The loss of eggs and fetuses can be reduced by improving the health of the herd and by avoiding virus infections at critical stages during the life cycle.

A possible method of reducing prenatal death is to use hetero-insemination (semen from two or more boars within one heat). Meding (1979) showed an increase in litter size by 0.3-0.4 piglets per litter by using this method.

POSTNATAL DEATH

Concerning post natal death, it has been shown in many trials and surveys that up to 20 percent of all liveborn pigs die within the first 8 weeks of life.

Preweaning mortality should be seen in relation to litter size, because the mortality will increase with litter size. In large litters, problems such as trauma and hunger will be of great significance. In large herds it will be possible to reduce the losses, if many sows farrow at the same time. It is thus possible to transfer pigs from large litters to sow with only a few piglets. However, if this is to be successful, it must be undertaken in a way which gives all piglets an opportunity to receive colostrum.

PRACTICAL ASPECTS OF IMPROVING SOW PRODUCTIVITY

Wrathall (1977) presented a system of recording reproductive performance in sow herds. The schedules suggested seem to be very useful in checking the performance of sows. However, several factors such as breed, mating procedure, general management, age at first mating, culling policy, feed cost and building expenses influence sow productivity.

It is well established that under equal production conditions crossbred sows produce more pigs than purebred sows, and the viability of crossbred pigs is better than that of purebred pigs (Jensen 1975). The heritability of reproductive traits has been considered to be rather low. However, recent studies indicate that selection may be a feasible way of improving the productivity of a sow herd (Skjervold 1977; Bereskin 1980). Under practical conditions the variation in fertility of boars should be taken into consideration as it is well established that boars have influence upon conception rate and litter size (Christensen & Pedersen 1978). To bring the sow in heat quickly after weaning and to detect the heat, it is recommended that sows be housed adjacent to mature boars. There is no doubt that the low reproductive performance which is seen in many herds is caused by a poor heat detection and mating procedure. Sows should be served twice within the estrus period, and Meeding (1979) suggested to use two different boars to increase conception and litter size. Conflicting opinions exist about optimum age of mating gilts. Brooks & Smith (1980) suggested mating at second heat but as early as possible, whereas O'Grady (1979) recommended not to mate before the gilts had reached 240 days of age. However, Aherne (1979) suggested the following system which seems to be very useful in a sow herd with growing-finishing pigs. Gilts and castrates should be penned separately immediately after weaning. When gilts reach a weight of approximately 65 kg, mature boars are penned adjacent to the gilts. All gilts showing strong and consistent heats are potential sows, and gilts are mated at their third heat. In this way, genetics, conformation and suitability can be taken into consideration, and it may be possible to improve the consistency of heats in the herd by selection. This method can easily be applied in a batch farrowing system as suggested by Nielsen & Danielsen (1976).

There is a high wastage rate in sows. The main causes of wastage are reproductive difficulties, leg problems and small litters (Tomes & Nielsen 1979). It is important that sows to be culled are excluded from the herd as soon as possible after weaning. Finally, it should be mentioned that cost of feed and buildings can have a marked influence upon the economic return of a sow herd.

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The Producer's Role in Health Management

MICHAEL R. WILSON

The swine producer, because he owns the pigs, is the major decision-maker in a swine production unit. The decisions include those that affect health. Health can be very simply defined to include anything that affects the productivity and profitability of an enterprise. Using this definition, disease is only one of the factors affecting health.

The most important decision that needs to be made is the order in which problems are to be tackled. This assumes that problems, and their significance relative to each other, are recognized.

Factors affecting health are:

- Number of litters per sow per year
- Litter size
- Building cost and capacity
- Interest rates
- Preweaning piglet mortality
- Labour
- Post weaning mortality
- Growth rate
- Feed consumption
- Hog prices

Factors affecting the promotion of health, and concerning the animal and the recognition of problems will be discussed with a view to arriving at a hierarchy of problems to aid decision-making.

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Health Management in a Unit Producing Three Million Head Annually

DAVID D. MYERS

INTRODUCTION

Is it possible that a person who has devoted most of his professional life to the production of laboratory mice has anything to offer a Pork Industry Conference? I hope so, at least in principle.

First, animal breeders have to be concerned with: nutrition, proper physical environment, and disease control.

Second, there is only one biology and all life forms evolved together. Various organisms, including mammals and their disease agents, have developed complex interrelationships. The study of these interrelationships is called ecology and we must learn to think ecologically if we are to be successful in modern techniques of animal rearing. It is because of this common evolution and the similar development of host-parasite relationships be the host a plant, a mouse, or a pig that there is validity in general biological concepts of disease transmission and control, validity in the concept of animal models for human disease (the basis of laboratory animal science) and even validity in the concept of diseases of laboratory animals as models for diseases of "domestic animals of economic importance". I will present principles of disease transmission, disease control, with emphasis on how disease control has been approached in the production of laboratory rodents, and the potential application of laboratory animal rearing techniques to swine production.

SOURCES OF INFECTIOUS DISEASE

In order to control infectious diseases, the source of disease must be known. Basically, the sources of infection are 1) elements of the inanimate environment such as soil and water, and 2) animals, including swine themselves and many other species, as well. Examples of disease agents that may be found in soil, include the cause of swine erysipelas, *Erysipelothrix rhusiopathiae* (Wood and Packer, 1972); the cause of listeriosis, *Listeria monocytogenes* (Blenden, 1970); and roundworm eggs, *Ascaris lumbricoides var. suis* (Twiehaus and Underdahl, 1970). Those found in water include, *Pseudomas aeruginosa* (Hugh and Gilardi, 1980), a cause of wound infections and a participant in several other disease entities, and *Leptospira pomona*, a cause of leptospirosis (Alexander, 1980).

More important, however, are those infections carried by animals themselves. These are too numerous to mention in detail within the scope of this discussion, but some important generalizations can be made, First, the carrier need not come

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on the premise itself since materials that may be brought onto the farm, such as bedding or feed, may be contaminated by the feces of infected rodents or birds. Feed may also contain milk products, fish meal, meat scrapes, bone meal from animals carrying disease (Sorenson, 1970). There is also the possibility of men being mechanical carriers, having carried organisms from one premise to another on hands, shoes, or contaminated tools and instruments, etc. Flying insects, dogs, cats, and birds may also mechanically transfer infectious agents from place to place. Second, disease agents of swine may be carried by a wide variety of other species such as snakes that carry Salmonella (Hinshaw and McNeil, 1945). fish that carry erysipelas (Shulman and Wood, 1970) or calcivirus (Smith *et al.*, 1980), cattle, sheep, dogs, and cats that carry pseudorabies (Gustafson, 1970), cattle dogs, and rats that carry Leptospirosis (Alexander, 1980), birds, rodents, dogs, and cats that carry Salmonella (Bruner and Gillespie, 1973), chickens that carry tuberculosis (Karlson, 1970) and man that may carry a whole host of agents, including *Bordetella bronchiseptica* (Switzer, 1970) and pathogenic *E. Coli* (Martin and Washington, 1980). Third, these carriers will very likely be in apparent good health. Four, the outcome of exposure of individuals or herds are influenced by numerous factors such as the dose of the agent, the genotype of both the parasite (agent) and the host, the age and sex of the host, previous contact of the host with the agent, the nutritional status of the host, degree of environmental stress, pre-existing parasite or disease burden, and the population density of the host animals. Thus, at times exposure may result in no infection, inapparent infection that does not persist, persistent inapparent infection, persistent infection with periodic disease outbreaks, the appearance of disease followed by complete disappearance, or the appearance of disease of varying severity which is transmitted from generation to generation. The point is that it may be difficult to associate the contaminating event with the reduced thriftiness or recognizable disease that may ensue. It is, therefore, necessary to adopt good disease prevention practices as a matter of faith, even though sometimes it appears possible to adopt less stringent measures.

METHODS OF DISEASE CONTROL

Although there are many methods for dealing with diseases, the ultimate method is to prevent infection. This requires the elimination of the agent and prevention of all future contact with the agent. There are several ways that infectious disease agents can be eliminated from a group of animals including: 1) medication, disease monitoring, and management practices to prevent infection, 2) test, slaughter and quarantine, and, 3) exclusion of young from adults through removal at birth, or by hysterectomy derivation, followed by rearing on artificial milk in strict isolation from other swine.

The latter method has been widely used in the production of laboratory rodents, and has the advantage of simultaneous elimination of any infection that can not breach the ovarian or placental barriers. Similar methods of producing disease-free stocks of swine were also developed at about the same time, or slightly earlier, in the mid 1950's (Twiehaus and Underdahl, 1970). The techniques for obtaining and rearing disease-free animals were, of course, developed by workers such as Reyniers, whose interest was in germ-free life (reviewed by Myers, 1980). With laboratory rodents there has been considerable emphasis on keeping the animals free, not only from infections of economic significance, but from subclinical infections that might cause disease in stressed animals, or that could interfere in subtle ways with research findings (Pakes and Benirschke, 1971). Because of those absolute necessities, the concept of housing the disease-free animals in "Barrier" buildings has been widely utilized. In addition, various techniques

and equipment have been developed to reduce the possible spread of disease within the barrier.

The goal in the design of a barrier building is to insure that nothing, including people, enter the building without being processed in some way to prevent or greatly reduce the probability of the introduction of infectious agents. Thus, a typical rodent barrier building would have the following features: positive air pressure, personnel entry locks, materials locks, pass-through cage and equipment washers, pass-through steam sterilizers, automated hyperchlorination or acidification of drinking water, a two corridor system (figure 1), and rodent-

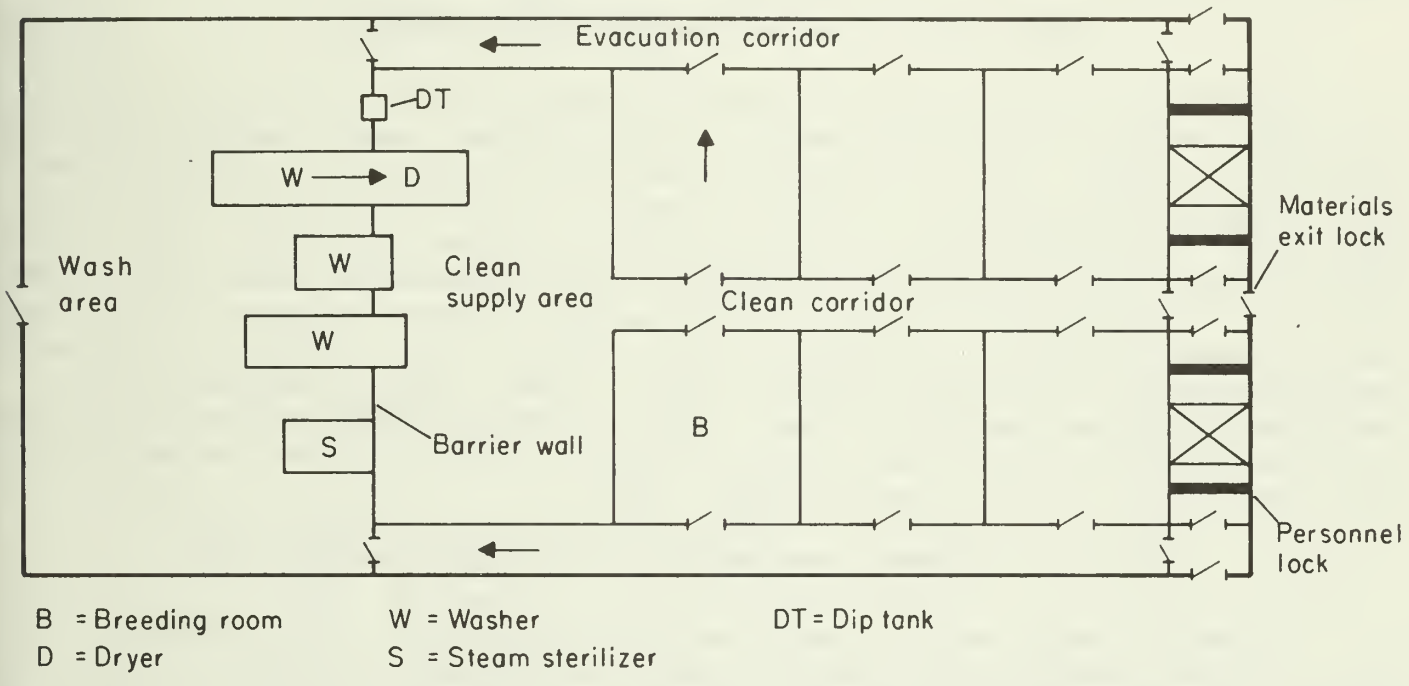

Figure 1. Barrier concept in rodent breeding.

proof construction. The air supply is filtered and the temperature and humidity controlled; these features virtually eliminate the likelihood of airborne introduction of infection, help control the entrance of flying insects, control odors, and by providing optimal humidity, reduce microbial viability in the air. Personnel entry locks provide for a complete clothing change to eliminate mechanical introduction of infectious agents by people, and also provide for hand washing or showers. In many facilities, personnel wear surgical scrub suits, caps, and face masks. Bedding material, clothing, and most supplies are steam sterilized before entry. Some supplies may be sterilized with ethylene oxide, or passed through a disinfectant bath. Food is either sterilized by gamma rays, or by steam, or processed (Pasteurized) to kill nonspore-forming bacteria. If cages and other equipment leave the breeding room they are passed through a mechanical washer at (180-190°F) or steam sterilized before being returned to a breeding room. Workers who handle the soiled or "dirty" equipment can not touch clean equipment, because of the barrier design and "pass-through" washers and sterilizers. The two corridor design helps isolate breeding rooms from one another by keeping "clean" equipment and supplies from contacting "dirty" materials prior to entering a breeding room. Hyperchlorination or acidification of drinking water virtually eliminates Pseudomonas infections. Colonies are essentially closed and visitors are either not permitted or are rigorously controlled.

Other provisions for reducing the spread of infections range from the elementary to the highly sophisticated. Simple equipment includes fabric hoods over cages, and the use of disinfected forceps, or gloved hands for handling animals. More sophisticated equipment include mass air displacement and laminar flow ventilation systems, in which rooms are flushed with a very high volume of air (approximately 150 air changes per hour) that has been filtered through high particulate arresting (HEPA) filters. This technique keeps airborne dust, bacteria, animal proteins and even viruses to a minimum, and appears to reduce the spread of disease. The laminar flow designs attempt to minimize animal to animal contact even further through a unidirectional air flow. The laminar flow principle is also incorporated into fabric enclosures and portable cabinets that can be placed within animal rooms. Another approach is to keep cages within various types of ventilated enclosures, or to actually provide an air supply to each cage.

PERFORMANCE OF DISEASE-FREE RODENT BREEDERS

Some major suppliers of laboratory mice presently provide animals free of known mouse adapted infectious agents, but the mice may harbor organisms that are widespread in nature, such as *Pseudomonas aeruginosa*, or bacteria carried by people. Other colonies of mice and other rodents may have one to three organisms which should be susceptible to eradication, but which may require the very expensive and disruptive procedure of depopulation, decontamination, and repopulation (See Myers, 1980 for review). For the most part, the great progress that has been made has been through the procedure of hysterectomy derivation without using medication or vaccine. At least one major mouse breeder, however, has greatly improved the health status of its colony through a strict closed colony policy, utilization of a barrier facility, limited medication, and emphasis on sanitation, and contamination control (Les and Myers, 1978).

RELEVANCE OF RODENT REARING PRACTICES TO PORK PRODUCTION

As swine rearing methods swing more and more towards close confinement, high population density practices, the parallels to rodent rearing increase. Certainly, the techniques of hysterectomy deviation and barrier rearing are based on the same general phenomena for both species, and are equally valid for both. Once a farm or pig rearing facility has been populated with disease-free animals, isolation procedures appropriate to the situation should be instituted. The most dangerous animal to a disease-free pig of any description is another pig, and the introduction of new breeding stock should be done with great care. Probably the next most serious threat, because of his propensity to visit other farms, is man. With some thought and discipline, any farm can incorporate quarantine and visitor control procedures. The continuing trend towards intensive confinement rearing, the investment in facilities, and the number of animals at risk would seem to make the utilization and strict operation of barrier procedures a necessity, particularly with respect to introduction of breeders, personnel entry procedures, air and water treatment, rodent and insect control and material entry and exit. It may not yet be feasible to pasteurize or sterilize feed, although large rodent facilities easily process 10-15 tons of feed weekly.

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Leg Weakness in Swine

FRANK X. AHERNE AND T. NAKANO

The aspect of the feet and leg problem of swine that I will discuss deals with a degenerative joint abnormality. The condition has been classified into two broad categories based on clinical signs. The first category includes disturbance in the formation of bone beneath the joint cartilage and is known as osteochondrosis (Grondalen 1974a). The second category includes degenerative lesions of the articular cartilage without apparent disturbance of bone formation and is known as osteoarthrosis (Grondalen 1974a). In both cases, the joint damage is not attributed to bacterial infection. In advanced cases of osteoarthrosis the articular cartilage of the joint shows grooves, depressions and fractures and may be eroded from the subchondral bone (Grondalen 1974a). In advanced osteochondrotic joints the articular cartilage may show morphological alterations such as thickening, softening and fracture of the cartilage. Also due to failure of ossification, the bone surface beneath the articular cartilage is collapsed or uneven and may have small pieces of cartilage embedded in the bone near the osteochondral junction (Nakano *et al.* 1979a,b). The joints most commonly affected are the knee and elbow joints. Within these joints lesions are frequently observed in the distal humerus, distal femus and proximal ulna (Nakano *et al.* 1979a, Grondalen 1974a).

The incidence of osteochondrosis in young and mature swine is hard to estimate. In various countries of the world it has been reported that 10 to 30% of boars in performance test stations are culled because of leg weakness (Grondalen *et al.* 1976, Bereskin 1979). In many surveys of sow reproductive performance the second most frequent reason for culling sows, after reproductive problems, is because of leg weakness. Post mortem data on growing-finishing pigs in several countries have shown that 80 to 100% of market weight hogs have one or more joints affected by osteochondrotic and/or osteoarthrotic lesions of varying degrees of severity (Elliot and Doige 1973, Grondalen 1977, Reiland 1976, 1978b). Only advanced stages of these lesions result in lameness in animals. Our studies have shown that if a hog has lesions on the distal humerus, proximal ulna and distal femur there is a high probability that the pig will be lame (Nakano *et al.* 1980). However, Reiland (1978a) reported that signs of leg weakness showed no significant correlations with severity of joint lesions. Similar observations have been made by Fredeen and Sather (1978).

Our results suggest that lameness in pigs does not significantly reduce average daily gain or feed conversion efficiency. In fact, Bereskin (1979) reported a moderate positive genetic correlation (.33) between growth rate and feet and leg problems.

The high incidence of joint lesions in growing pigs is often attributed to

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the current intensive methods of production and confinement rearing systems (Grondalen 1977). In particular, rapid growth rate, lack of exercise, changes in the conformation of our pigs and floor type have been implicated as important causative factors (Vaughan 1971, Pointillart and Gueguen 1978, Reiland 1976).

Rapid growth rate in modern pigs has meant that pigs are reaching market weight at younger ages. Thus, joint cartilages have to withstand greater weights while relatively immature. Because of this, it has been frequently suggested that lowering growth rate by restricting feed intake will reduce the incidence of joint lesions and leg weakness (Walker and Jones 1962, Reiland 1978b). However, in our study (Perrin *et al.* 1978) there was no significant relationship between growth rate and the incidence and severity of joint lesions. Duthie and Lancaster (1964) and Fell *et al.* (1970) were also unable to show that the incidence and severity of lesions associated with leg weakness were related to fast growth rate of pigs. In contrast, Grondalen and Vangen (1974) studied genetically selected rapid and slow growing lines of Norwegian Landrace pigs and found a significantly higher incidence and severity of joint lesions in the rapid growing than in the slow growing lines. However, it should be noted that the incidence of lesions in these lines was very high even in the slow growing line (94.6%). These data suggest that important etiological factors other than growth rate contribute to the incidence of joint abnormalities in pigs.

EFFECTS OF SEX

It has generally been suggested that leg weakness and the lesions in articular cartilage associated with it have occurred more often in growing boars than in gilts or castrates (Walker and Jones 1962, Bullough 1969, cited by Weiss *et al.* 1973).

However, Nakano *et al.* (1979a) and Fell *et al.* (1970) suggest that there is no difference in the incidence or severity of joint lesions among boars, gilts and castrates.

EFFECTS OF BREED AND GENETICS

Duthie and Lancaster (1964), as a result of a field survey which showed that several breeds of pigs were affected by leg weakness, suggested that breed and genetics were not major factors contributing to the incidence of articular cartilage lesions. Perrin *et al.* (1978) reported no significant difference between Yorkshire and crossbred pigs in the incidence or severity of arthrotic lesions. Grondalen (1974b) reported a lower incidence and severity of osteochondrosis in Yorkshire than in Landrace pigs. Reiland *et al.* (1980) also reported that the incidence of joint cartilage lesions was significantly higher in Landrace than in Yorkshire or Hampshire swine.

Conformation of body is emphasized by some researchers as being a critical factor in the incidence of leg weakness in swine. Breeds or strains of pigs with longer bodies, broader hindquarters and shorter femurs appear to be more frequently affected with leg weakness (Pointillart and Gueguen 1978, Grondalen 1974c, Grondalen and Vangen 1974). Miller (1978) cited by Bereskin (1979) suggests that the incidence of osteochondrosis can be reduced by visual selection of proper type of breeding stock, that is, animals more level in the top line, longer and more sloping in the front and rear pasterns and having even toe size on each foot. Estimates of the heritability of leg weakness have ranged from very low

(Smith 1966) to moderate (0.15-0.30) (Bereskin 1979), to a high of 0.5-0.6 by Teuscher *et al.* (1972). Based on these estimates, breeders could expect to make slow to moderate progress in eliminating leg weakness from their herds by careful appraisal of the animals selected for breeding.

EFFECTS OF NUTRITION

Because of the importance of calcium, phosphorus and Vitamin D in bone growth and development, it has been frequently suggested that deficiencies of these nutrients may be involved in the development of "leg weakness" in pigs. However, varying the calcium, phosphorus or vitamin D concentrations and the calcium to phosphorus ratio did not effect either the incidence or severity of joint lesions or the clinical signs of leg weakness (Pond *et al.* 1978), Grondalen 1977, Duthie and Lancaster 1964, Walker *et al.* 1966). According to Walker *et al.* (1966), the addition of Vitamin C to rations did not prevent the onset of ulnar lesions and they reported that the Vitamin C status of the affected pigs was satisfactory, as judged by blood plasma ascorbic acid concentrations and urinary excretion of ascorbic acid. Walker *et al.* (1966) also stated that the Vitamin A status of affected animals appeared to be satisfactory as judged by the high concentrations of the Vitamin A in the liver of a number of boars suffering from leg weakness and showing ulnar lesions. They also reported that they observed typical ulnar lesions in boars given diets containing 142 ppm of manganese and supplemented with copper. Grondalen (1977) reported that supplementation of swine diets with magnesium, copper, zinc and manganese within wide limits did not have any significant influence on the incidence and degree of osteochondrosis.

EFFECTS OF MANAGEMENT

Lameness in swine has been attributed to lack of adequate exercise under confinement rearing. Elliott and Doige (1973) and Fredeen and Sather (1978) found that individual penning of growing pigs resulted in more locomotor problems than in pigs penned in groups with approximately the same floor area per pig. The authors considered the results to be primarily the result of muscular weakness or a lack of muscle tone attributable to a lack of normal exercise. Such lack of exercise results in reduced joint movement which is necessary to promote diffusion of nutrients from the synovial fluid to the articular cartilage. The observation of Duthie and Lancaster (1964) that the general husbandry and health of pigs were better than usual on farms where leg weakness occurred with a high frequency indicates that there may be some relationship between leg weakness and intensive management.

Floor surfaces can result in severe foot injuries and could result in changes in the way the pig walks. Such changes could alter the angles at which bones meet in the joints and thus lead to a shift in the areas of the articular cartilage upon which the greatest degree of pressure is exerted. If such areas of the cartilage are not suited to this increased weight load, the result may be damage to the cartilage or subchondral bone. Vaughan (1971) suggests that softer flooring such as grass and earth provides a more secure footing than does slippery concrete for limbs with defective posture and may prevent severe clinical lameness. However, in our experiments (Perrin *et al.* 1978) there was no significant difference in the incidence or severity of arthrotic lesions between pigs raised on concrete floors and earth floors covered with straw.

RECOVERY FROM OSTEOCHONDROSIS

It has frequently been suggested that pigs culled in swine performance testing stations because of abnormal feet and legs will recover if they are housed on pasture or in dirt lots. McPhee and Laws (1976) reported that 30 out of 73 boars recovered from leg weakness within four weeks of returning to a farm environment. In contrast, Nakano *et al.* (1980) reported that there was no evident improvement in locomotory ability of lame boars when they were penned in dirt lots. On post mortem, the elbow and knee joints were seen to be affected with severe osteochondrotic lesions.

It is clear that at present the etiology of osteochondrosis and osteoarthrosis is not well understood. Until we understand the primary cause of these conditions, it will be difficult to recommend methods of curing or preventing the disease.

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Feet and Leg Soundness in Swine

ROBERT D. FRITSCHEN

Of the numerous components of the pig's environment the one he is least able to disassociate himself from is the surface he must stand or lie on. For thousands of years the pig has remained unchanged, adapting to nature under a wide range of conditions. Advances in technology, especially during the past quarter century, often appear antagonistic to the pig's natural ability to adapt. Unquestionably, modern housing management systems result in more stress to feet and legs than preconfinement production. Modern cropping practices that maximize yields and artificially dried or high moisture feed grain may have a subtle effect on the chemistry of the grain. Altering the genetic composition of the pig by continuous selection for one trait such as growth rate or muscle development without regard for total production may have opened the door to more complex problems. From a traditional viewpoint, markedly different housing/management, cropping/nutrition and genetic emphasis all descended upon the pig nearly simultaneously and with an intensity that may challenge or alter the structural mechanism of the pig.

There are several features of the pig's claw that under confined conditions result in somewhat characteristic lesions. Penny *et al.* (1963) in a slaughter house survey in England reported that the average ratio of length of outer claw to inner claw was 1.11:1 and average width was 1.13:1. Of the 3195 pigs examined (background unknown) 65 percent had claw lesions. Since this study took place over a year's time, all seasons were included. Fritschen (1973) found the same discrepancy in claw size but noted that the amount of slotted floor the pigs were raised on had an effect on claw dimension as shown in tables 1 and 2.

Table 1. Average outside and inside claw lengths on 25 and 100% slotted floors

Percent Slotted Floor	100	25	Av.
Outside claw (inches)	1.71	1.82	1.77 (a)
Inside claw (inches)	1.42	1.53	1.48
Av.	1.57	1.68 (b)	

(a) Outside claws significantly longer than inside claws ($P < .001$).
(b) Claws on 25% slotted floor significantly longer ($P < .005$) than on 100% slotted floor.

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Table 2. Average outside and inside claw widths on 25 and 100% concrete slotted floors

Percent Slotted Floor	100	25	Av.
Outside claw (inches)	1.13	1.10	1.12[a]
Inside claw (inches)	1.03	0.99	1.01
Av.	1.08	1.04	

[a] Outside claws significantly wider than inside claws ($P < .01$).

These data show that outside claws are larger than inside claws and that 100 percent slotted floors have a greater wearing effect than 25 percent slotted floors. This study also suggests that on a partially slotted floor a slight accumulation of organic material on the solid portion may insulate the volar surface of the pig's claw from the abrasive characteristic of the concrete. This same study revealed that the outside claw did sustain a greater level of lesions than the inside claw (table 3). This strongly suggests that the unequal claw size results in unequal weight distribution and that this may be a factor in lesion development and distribution.

Table 3. Relationship between outside vs. inside injury score and percent concrete slats

Percent Slotted Floor	100	25	Av.
	Injury score [a]		
Outside claws	3.87	3.54	3.71 [b]
Inside claws	3.00	3.20	3.10
Difference	0.87 [c]	0.34	
Av.	3.44	3.37	

[a] Injury score - 1 is normal, 5 most severe.
[b] Injury score significantly greater on outside claw ($P < .001$).
[c] Interaction between claw x slat significant ($P < .025$).

In England the emphasis on lameness research has been confined to pigs reared primarily on concrete. A study by Wright *et al.* (1972) sought to determine if rough surfaces that were clean or dirty resulted in more lesions than a smooth concrete surface that was clean or dirty. The results shown in table 4 suggest concrete that is rough causes more lesions than smooth concrete. The effect of clean versus dirty conditions is less clear but once the lesions are present it can be theorized that dirty conditions may predispose to a buildup in the pathogen level on the walking surface; this may cause infection and enhance lameness. This and other studies from England prompted these workers to conclude that the abrasive characteristic of concrete was responsible for most claw lesions among confinement reared swine.

Surfaces or slats of various materials are available to the industry. Fritschen (1974) studied the claws of pigs reared on either soil or 100 percent

Table 4. The influence of a rough and dirty floor surface on the incidence of moderate and severe foot lesions.

Surface	No. of pigs	Number with lesions			
		Nil	Mild	Moderate	Severe
Dirty rough concrete	24	0	3	13	8
Clean rough concrete	24	0	7	10	7
Dirty smooth concrete	24	2	14	8	0
Clean smooth concrete	24	5	15	3	1

slotted floors made of steel, concrete or aluminum. The results shown in figure 1 indicate that aluminum slats caused a greater level of lesions than concrete or steel slats and that soil resulted in a low incidence of claw lesions.

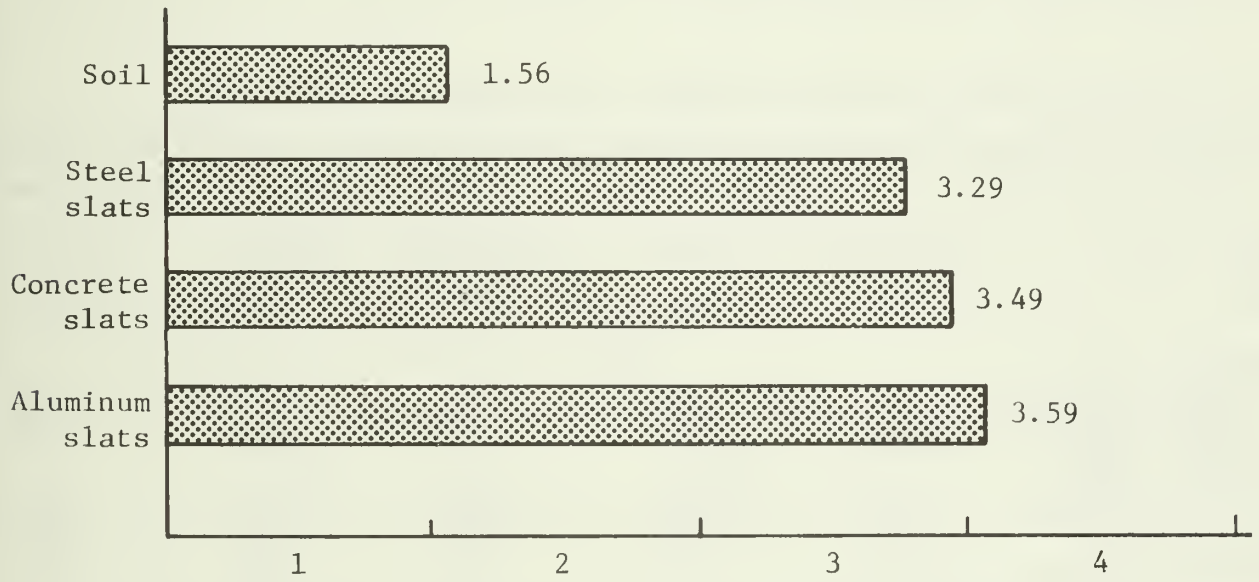

Figure 1. The effect of slat type or soil on claw injury level. Score of 1 is normal, 5 most severe.

This study was not in agreement with the English conclusion regarding concrete and claw lesions. The results of the Nebraska study suggested two possibilities: (1) surface characteristics in addition to abrasiveness are responsible for claw lesions and that the characteristic common to aluminum, concrete and steel is lack of resilience at the claw-floor interface and, (2) the question is raised but not answered, "Could there be a chemical reaction between body salts excreted in the feces, the aluminum slats and tissue, on the volar surface of the claw?" The study did agree somewhat with other workers as it resulted in smaller claws among concrete reared pigs indicating a greater wearing effect. However, it appears that wear per se is not the only factor or perhaps even the most important factor leading to claw lesions.

A similar study was conducted by Fritschen and Zoubek (1975) adding other slat materials to the comparison. The experimental procedure and results are shown in tables 5 and 6.

Table 5. Experimental procedure

Type floor	No. of pens	No. pigs per pen	Total pigs	Sq. ft. per pig	Av. bg. wt. (lb.)	Av. final wt. (lb.)
50% solid concrete-50% concrete slats[a]	3	5	15	8.8	25.9	202.8
50% solid concrete-50% plastic slats[b]	2	10	20	9.2	25.8	193.5
100% plastic slats[c]	4	5	20	9.0	25.8	192.4
100% steel slats[d]	1	20	20	9.2	25.3	194.2
100% aluminum slats[d]	1	20	20	9.2	25.7	191.1

[a] Slats 4" wide with round edges and laid at right angle to long dimension of pen. 1" slot.
[b] Slats 5" wide, 3/4" slot, pvc solid surface slats laid parallel to long dimension of pen.
[c] Same as "b", only 100% slotted.
[d] Slats 3" wide with 7/8" slot.

Table 6. Effect of slat percent and type on claw injury level[a]

Amount and type of slat	Front claws		Rear claws		Average claw injury score
	Outside claw	Inside claw	Outside claw	Inside claw	
50% plastic slats-50% solid concrete	1.81	1.97	1.23	2.70	1.93
100% plastic slats	2.42	2.17	2.05	3.35	2.50
50% concrete slats-50% solid concrete	2.77	2.50	1.87	3.33	2.62
100% steel slats	3.12	3.10	2.12	2.95	2.82
100% aluminum slats	3.52	3.62	2.17	3.52	3.21

[a] The greater the degree of injury the greater the numerical value.

Floors that were half plastic slats and half solid concrete resulted in a lower level of claw lesions. The rational would suggest that if 50 percent plastic slotted floors reduced claw lesions that 100 percent plastic slats would reduce them even more. Why the level of lesions on 50 percent plastic slats was less than on 100 percent plastic slats was unexplained at the time. Even though the floors with plastic slats resulted in less claw lesions it was noted that, especially during the finishing period, they were slippery and the pigs were less mobile when walking on them. In this study, pigs were housed in three different buildings. Therefore, comparisons of gain, feed:gain and their relationship to claw injury could be made only between different floor types in a common building. This is shown in table 7 and indicates that the level of claw lesions has little effect on gain or feed:gain. This conclusion is in agreement with the English workers. However, since pigs with claw lesions may stand or walk in an abnormal manner to relieve their discomfort, undesirable leg characteristics often result.

This suggests that the total problem may not be the same for the pig destined for the breeding herd as for the pig going to market.

Table 7. Relationship between performance and claw injury and slat type

Amount and Type of Slat	Average [a] Injury Score	ADG	F/G
Building F			
50% plastic slats- 50% solid concrete	1.93	1.44	3.18
100% plastic slats	2.50	1.42	3.04
Pig Poke			
100% steel slats	2.82	1.44	2.97
100% aluminum slats	3.21	1.41	3.08

[a] Higher value = greater injury.

Some consideration for the pig's physical ability to adapt to various walking surfaces must be given. The distinctly different types of tissue making up the pig's claw render adaptation to a very wide range of surfaces predictably low. Table 8 summarizes a study (Fritschen and Cunningham, 1974) with pigs grown to a weight of about 117 pounds on either soil or 100 percent concrete slats and then their locations reversed. Claw length, width and injury score were made at the end of each phase of the study.

Table 8. Soil or concrete reversal study

Phase [a] No.		Weight lb. 1 and 2	Surface type 1 and 2	Injury score 1 and 2	Length In. 1 and 2	Width In. 1 and 2
Group I	1.	30-117	Soil	1.54 [b]	1.51 [c]	1.04
	2.	117-193	Concrete	4.12	1.62	1.12
Group II	1.	30-124	Concrete	3.57	1.48	1.02
	2.	124-204	Soil	2.38	1.63	1.11

[a] Phase 1 = 77 days; phase 2 = 52 days.
[b] Includes mean score of 8 claws on 20 pigs. Higher value = greater injury.
[c] Rear claws only.

The Group I pigs had a very low injury score at the end of phase 1 on soil but had a much greater degree of injury at the end of phase 2. However, allowing pigs to become adapted to soil and then being moved to concrete resulted in the apparent rapid and severe onset of lesions. This suggests that pigs can be moved from concrete to soil and the adaptation is fairly rapid and beneficial. These data also suggest that there was very little claw growth during phase 2. Assuming a 200 pound terminal weight, most of the claw size is attained by the time the pig reaches approximately 120 pounds. This indicates that as the amount of body mass nearly doubles, the area of the claw remains nearly constant. Therefore, the load-bearing surface of the claws has the effect of decreasing drastically near market weight.

A further study by Fritschen (1976) showed that pigs reared on eight inch wide concrete slats resulted in much fewer and less severe claw lesions than pigs reared on five inch wide plastic slats (table 9).

Table 9. Effect of slat width or type on average outside or inside claw injury score [a]

Type slat	Outside claw	Inside claw	Average
8" wide concrete	2.7	2.4	2.5
5" wide plastic	3.8	3.1	3.4

[a] Injury score 1 to 6 with 1 being normal.

Because of the confounding of experimental variables in table 9 (width, 8" versus 5" and type, concrete versus plastic) it is difficult to pinpoint the exact cause of the differences. However, it was concluded that pigs reared on the eight inch wide, flat, smooth surfaced concrete slats with a pencil-round edge had fewer and less severe claw lesions than pigs reared on five inch wide, plastic slats. This study suggested that wider slats may result in less severe claw lesions because wider slats represent fewer inches of slat edges than five inch wide slats. This statement is supported by the earlier study where 100 percent plastic slats resulted in more injury to the claws than 50 percent slotted floors. This makes a somewhat strong case for wider slats. It was noted that on the eight inch wide concrete slats that the pigs appeared very mobile and that the slats cleaned very well. In this research it was pointed out that concrete slats were flat, smooth (trowelled), and had pencil-round edges.

Fritschen *et al.* (1976) suggested that the pig apparently feels insecure as it walks on confinement floors. As a result, it tends to use the slat edge for traction and security. Since the tissue in the toe is relatively inelastic, tissue separation and subsequent bacterial infection often result.

Newton *et al.* (1980) found more hoof cracks on pigs housed on concrete than those housed on plastic, aluminum or porcelainizing steel. However, lesion scores were lower ($P < .01$) for steel and concrete than for plastic and aluminum.

A small but increasing number of field cases suggests that new concrete may predispose to lesions that are quite severe. However, the condition is not exclusively characteristic of new concrete as it has occurred on older concrete as well. Penny *et al.* (1971) reported on this problem and referred to a term in the literature called "lime-burning". They sampled the pH (table 10) of various areas of a pig unit, drinking water and cleaning agent, finding a wide range in end product pH. While the exact role of pH in causing lesions in apparently not known, it was reported that efforts to neutralize the surface pH or reduce the alkalinity resulted in a rapid abatement of the problem.

The role of nutrition in claw lesions and subsequent lameness has not been clearly expressed. The transverse cracking of claws has been associated with biotin deficiency (Adams *et al.* 1967). However, in view of the recent work incriminating floor surfaces the addition of biotin to prevent or cure any claw conditions must be done advisedly. Whether there are breed differences that interact with mineral deposition to various parts of the claw that may impart strength in unknown. Kovacs and Szilagyi (1972) reported that breed differences

were found when analyzing for certain elements in the toe and sole area of the claw. They reported that pigs with light pigmented (white) claw tissue had less calcium and magnesium than pigs with colored or dark claws. The effect of dietary levels of these elements on claw tissue level or subsequent conditions that may lead to or prevent lesions is totally unknown.

Table 10. The pH of wet concrete floor surfaces*

Site	pH water used	pH end product or water standing
Passageway	---	7.9
Passageway	6.9	8.4
Farrowing crate unwashed	6.9	10.0
Sow and litter pen, not washed	6.9	11.6
Sow and litter pen, washed once	6.9	9.1
Sow and litter pens, washed several times	6.9	9.6
pH of pig unit water supply	---	6.7
Calcium hypochlorite solution for washing down	---	12.0
Concrete floor in laboratory 3 yr. old	6.9	9.1

*Using Radiometer Copenhagen pH meter.

We probably know more about feet or claw problems as related to the environment then we do leg problems. Unfortunately and incorrectly we usually group "feet and leg" problems. In reality, factors resulting in problems to the claws generally do not result in problems to the leg structure. And conversely, factors resulting in leg problems generally do not cause problems to the feet. Regarding leg soundness, Bereskin (1979) suggested the heritability of soundness scores ranges from 20 to 30% with some variation between front and rear legs. This suggests that slow to moderate changes in leg structure may be made when systematic selection based on this trait is made. This aspect of the study was strictly phenotypic and subjective. As a result, it must be regarded as preliminary, interesting, but lacking specifics as a result of its subjectivity.

The opportunity for bone-nutritional interactions to result in lameness appears high. Rapid growth is a stress itself. Confinement, hopefully enhances fast growth by removing temperature extremes. Many times when a producer utilizes confinement, he will also improve other components of the enterprise such as nutrition and genetics. All or part of these changes will hopefully have the effect of improving growth rate. If this scenario is correct the stage may be set for osteochondrosis. This condition may be characterized by degenerative changes occurring in the basal layers of joint and growth cartilage, leading to a disturbance of endochondral ossification. These lesions were found in nearly all cases of "leg weakness" in animals younger than 18 months (Reiland 1976). Since fast growth apparently predisposes to osteochondrosis, the incidence must be widespread.

SUMMARY

The probably cause of leg or feet problems in confinement reared swine is complex. Nutrition or rapid growth may be involved in some leg problems but are less likely to be involved in feet problems. Diseases such as erysipelas, while occurring among confined herds, can be credited with only a small percentage of lameness cases. The incidence of lesions on the volar surface of the claw is great among confined swine. At least two references can be found relating claw lesions with structural abnormalities elsewhere on the leg. That claw lesions result in lameness in many cases is no longer speculative.

The cause and severity of claw lesions appear partly dependent upon micro-environment at the interface of the floor and claw. Roughness of the floor is a factor but perhaps not the leading factor as once was thought by some. Particles of the flinty portion of ground grain falling on a hard floor readily become imbedded in the pig's claw as it walks or stands. Probably the major factor leading to claw lesions in confinement relates to the anatomy of the claw. The range of tissue types making up the volar surface may be compared to an attempt to bond concrete and and sponge rubber. When a pig walks on soil both the soil and the tissue yield to the impact. To the pig walking on nearly all types of confinement surfaces only the tissue in the claw can yield. Since much of this tissue lacks, or is limited in elasticity, tissue damage results. Subsequent bacterial infection is nearly immediate because of the continuous contact of claw and floor. Then too, the linear inches of slat edges exposed to the pig is almost certainly a factor. The case for wider slats at least during growing-finishing and breeding-gestation is quite strong. Prolonged abnormally low humidity tends to desiccate tissue, predisposing to sand cracks and similar lesions.

The implications suggest that the near total lack of resilience in floors of confinement systems is at least the catalyst in most cases of claw lesions and lameness associated with it.

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Care and Management of the Neonatal Pig

HENNING E. NIELSEN

Mortality in piglets is very high. From surveys made in different countries on different breeds under various management and climatic conditions it is known that preweaning losses are 20-25 per cent of pigs born (Leman *et al.* 1972, Backstrom 1973, Aherne 1974 and Nielsen *et al.* 1974). Speer (1970) observed an even higher mortality rate. However, a great variation exists in mortality among production units, as in some cases the mortality rate even in large units, may be below 10 per cent (English *et al.* 1977). Thus it is an area of great potential. In many units it may be possible to save one pig per litter or two pigs per sow per year. This can be achieved by better care and management of the litter immediately after farrowing and in early lactation. Two pigs more per sow per year will mean a great increase in the gross return and although it will require more labour, it will undoubtedly also mean a higher profit from the herd.

Table 1. Causes of prenatal mortality in Danish herd

Main Group	Percent of dead piglets
Enteritis	16
Trauma	14
Anemia	14
Starvation	10
Constipation	9
Undersited piglets	7
Generalized bacterial infection	5
Congenital malformation	5
Peritonitis	4
Miscellaneous diseases	5
No established cause of death	11

Nielsen and Danielsen, 1979.

Table 1 shows data of major causes of preweaning mortality from a herd at a Danish experimental station. The causes of death as shown in Table 1 are in good agreement with results obtained in various surveys (Nielsen *et al.* 1974, English & Smith 1975). However, the number of piglets dying from anemia (Table 1) was extremely high, 14 per cent. The reason for the high mortality due to anemia was that a great number of piglets suffered from navel bleeding during the first day of life. Navel bleeding is a severe disease; affected piglets die from loss of blood due to their navel cords failing to dry up. The cause of navel bleeding is unknown but according to recent observations by Christiansen & Froseth (1978) and Danielsen *et al.* (1978) navel bleeding under practical conditions can be avoided by using straw bedding instead of wood shavings on the day of farrowing. In many

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cases death cannot be attributed to a single factor, as shown in Table 1 but are due to a combination of events.

Several recently published studies confirm the known fact that most death losses occur within the first few days (Maddock 1979). Nielsen *et al.* (1974) studied preweaning mortality in a number of Danish herds, and found that 58% of the losses occurred in the first three days. The data are shown in Figure 1. The data from Figure 1 underline the importance of the very early period in relation to losses. The number of stillborn are 5-9% of pigs born.

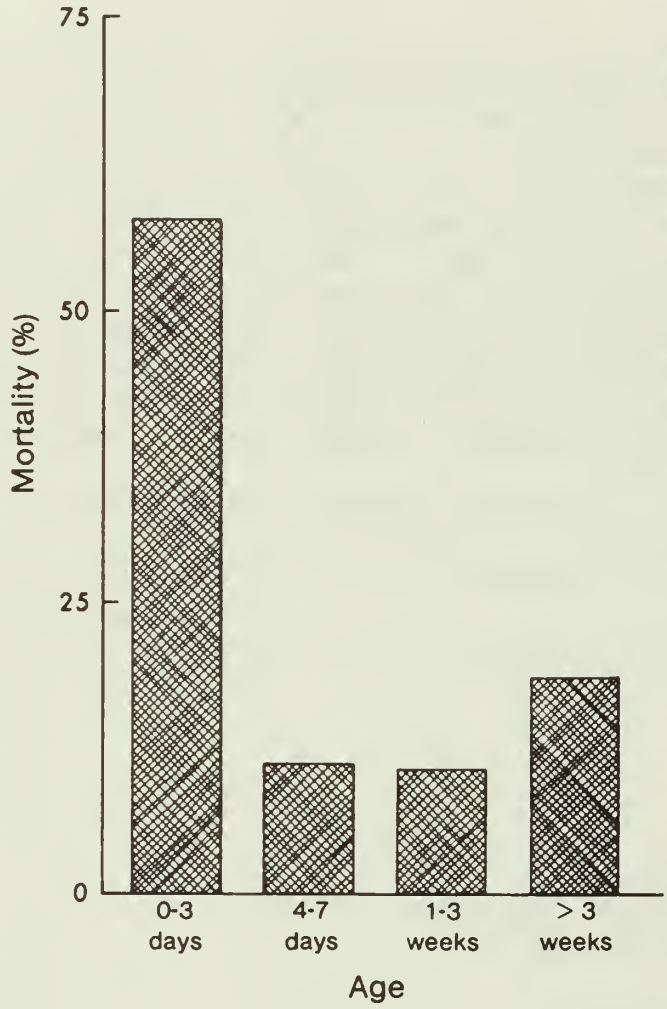

Figure 1. Preweaning mortality in relation to age of piglets.

FACTORS INFLUENCING BABY PIG MORTALITY

Litter Size

Litter size influences birth weight and survival. Large litters have lighter pigs. Table 2 shows the influence of litter size on weight gain and mortality. The mortality increased with increased litter size and it can be seen that the mortality is very high when litter size is more than 14 pigs. Although litter size at birth may have a harmful effect on pig survival rate, large litters at birth are still paramount to obtaining more pigs at weaning. Data from England & Day (1970) and Nielsen & Danielsen (1976) prove that with, proper supportive environment, pigs in large litters can be saved.

Table 2. Influence of litter size on birth weight, mortality rate and weight gain

No. of pigs in litter:											
Liveborn	>6	6	7	8	9	10	11	12	13	14	< 14
Still born	1.1	0.7	1	1.7	1	0.8	0.9	1.2	1.1	0.7	0.6
Birth weight, kg	1.54	1.74	1.59	1.50	1.49	1.45	1.43	1.41	1.36	1.38	1.31
Weight 3 wks, kg	6.3	6.0	6.2	5.5	5.4	5.2	5.1	4.9	4.7	4.7	4.4
Weight 6 wks, kg	12.2	13.0	12.5	11.4	11.2	10.7	10.8	9.8	10.1	10.0	9.7
Mortality to 6 weeks:											
No. pigs/litter	0.3	0.3	0.5	1.0	1.1	1.0	1.1	1.7	1.9	2.7	3.6
% of liveborn	7.7	5.0	7.1	12.5	12.2	10.0	10.0	14.2	14.6	19.3	23.2
Birth weight of dead pigs kg	0.80	1.66	1.31	1.42	1.48	1.15	1.24	1.29	1.14	1.15	1.20

Nielsen, 1975.

Birth Weight

Birth weight is one of the most obvious factors, and this has been substantiated by a number of studies i.e. pigs that survive are heavier than their litter mates that die before weaning. Typical of the data are those summarized in Table 3 from a Danish experimental station. The data agree with results, of Speer (1970) summarizing data from Iowa State University including 17,613 pigs from 1948 litters farrowed in crates with supplemental heat for the pigs, but unattended. The results are shown in Figure 2. Birth weight is not only important for survival rate but also for growth and development of piglets as shown in Table 4.

Variability Of Birth Weights

Variability of birth weights within litters has been found to have a significant effect on mortality. This relationship is illustrated by data from English & Smith (1975) and given in Table 5. Although the average birth weight was similar for litters with high and with low weight variability, mortality was lower in the litters with small variations in birthweights. There is less mortality in litters with pigs of equal weight, as then all pigs have an equal opportunity to nurse. There are no large pigs crowding out the small pigs.

Birth Interval

Birth interval was found by Hendrix *et al.* (1978) to be about 68 minutes less in pigs that survived to 21 days than in those that died. Randall (1972) found that the interval was longer preceeding stillborn pigs than preceeding liveborn pigs. Longer farrowing intervals may increase the severity of the prenatal asphyxia that occurs during delivery as a result of reduced respiratory gas exchange between the fetus and placenta (Curtis, 1974).

Sex

The sex of the pigs is also a factor of importance in relationship to baby pig survival. Figure 3 shows the relative mortality of males and female pigs. Although the males are generally heavier than the females, there is a higher mortality rate among males.

Genetic Background

Genetic background has been documented by a number of scientists to influence litter size and survival. Litter size, birth weight and survival have low heritabilities so that rapid changes cannot be made by selection. However, the heritability of litter weight at 21 days, which combines survival of pigs with milking ability of the sow is about 15% with a repeatability of 25%, (Zimmerman 1978) and is a desirable selection trait.

RECOMMENDATIONS IN ORDER TO REDUCE BABY PIG MORTALITY

Batch Farrowing

Batch farrowing is very important in relation to reducing piglet losses. Batch farrowing is automatic in very large herds as several farrowings will be taking place at one time. But if weaning is done at a certain day of the week a

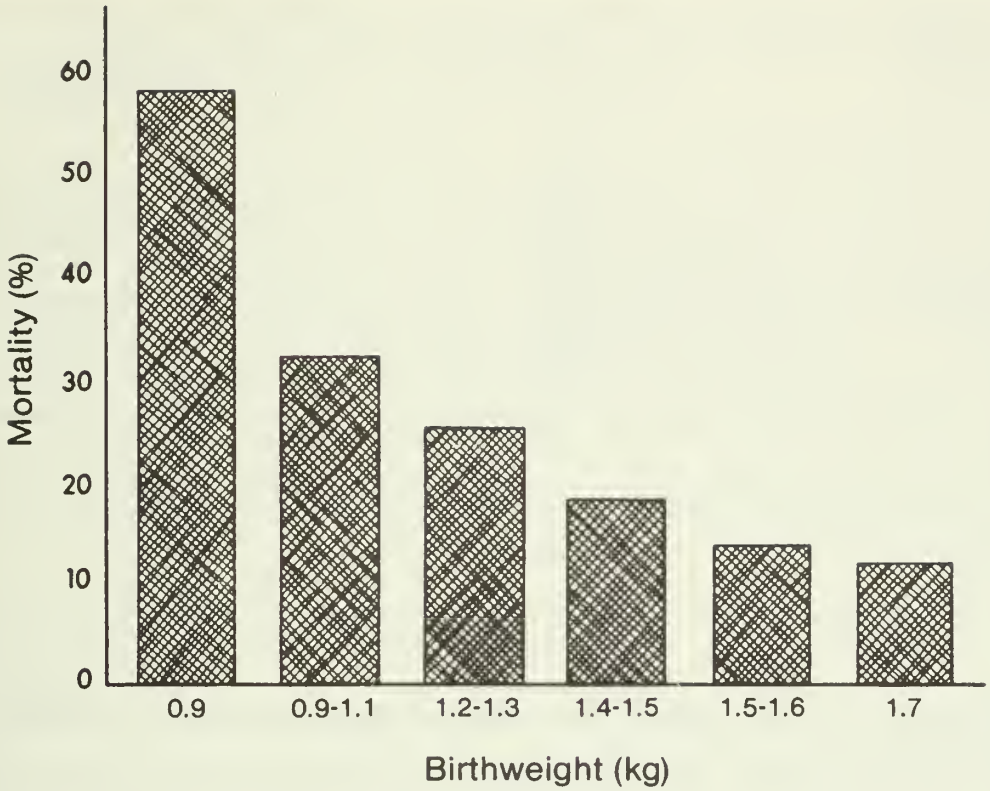

Figure 2. Relationship between birthweight and mortality.(Speer, 1970)

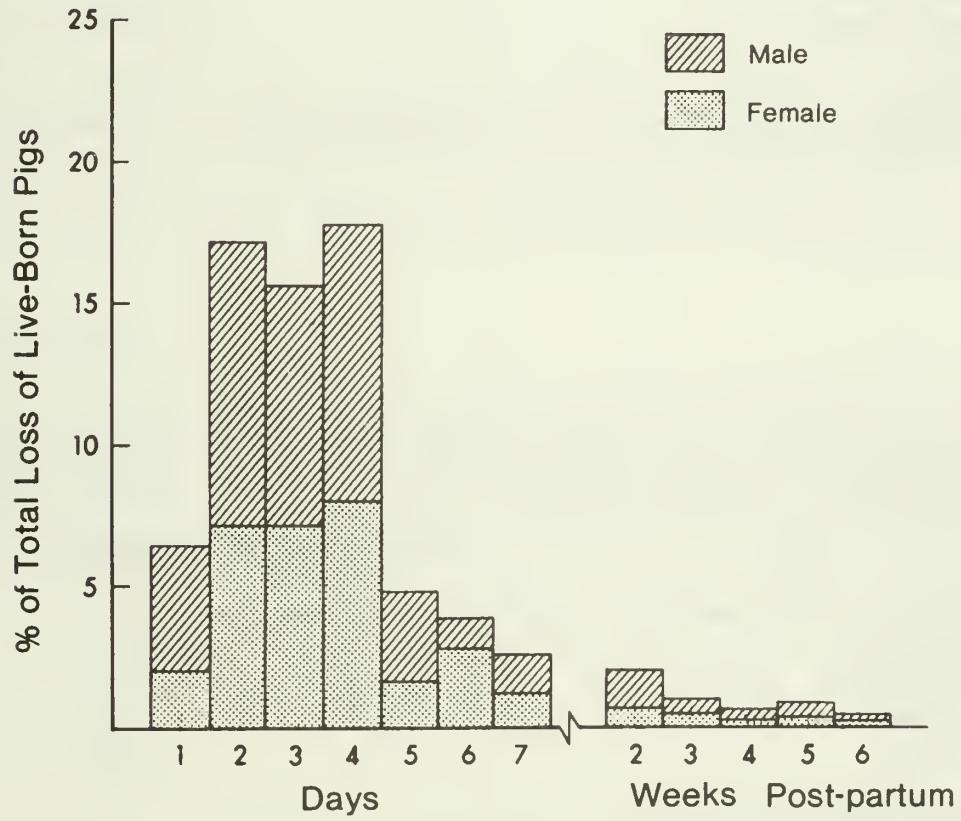

Figure 3. Relative mortality between male and female piglets.

Table 3. Influence of birth weight on mortality

Weight intervals, kg af birth	No. of pigs	Mortality % of liveborn
up to 0.90 kg	123	56.1
0.91 - 1.20 kg	416	20.4
1.21 - 1.40 kg	550	11.3
1.41 - 1.60 kg	637	9.1
1.61 - 1.80 kg	431	6.5
1.81 - 2.00 kg	159	6.9
Above 2.00 kg	46	8.7

Nielsen, 1975.

Table 4. Influence of birth weight on various characteristics in pigs

	Effect of .1 kg difference in birth weight
Weight at birth, average kg 1.45	...
Weight at 8 weeks, kg	0.7
Backfat thickness man	0.2
Area of cm long, dorsi cm^2	-0.16
Body length mm	0.4
Age at 90 kg, days	-0.3

Nielsen, 1975.

Table 5. Effect of within litter variability in birth weight on mortality

	Variation in birthweights	
	High	Low
Avg. birth weight, kg	1.07	1.10
Liveborn pigs/litter	11.4	11.3
Pigs weaned/litter	8.3	9.3
Mortality, percent	27.2	17.7

English and Smith, 1975.

large group of sows will be mated at the same day, and thus the chance of farrowing on the same day is great. This means that cross-fostering will be easy to practice as piglets from a number of sows farrowing on the same day can be interchanged and obtain colostrum from either their own mother or the foster-mother.

Indirectly, batch farrowing can give rise to a better hygiene in the herd. By practicing all-in all-out it is possible to efficiently clean and disinfect the unit. From a health point of view it is a great advantage to practice all-in all-out with pigs of the same age in each group. As far as labour is concerned it is an advantage to be able to do the same operation for many animals at the same time. Table 6 shows an example of the advantage of cross-fostering.

Table 6. Cross-fostering to equalize litters

	Control	Cross-fostering
Number of litters	18	18
Born alive/litter	10.9	11.0
Weaned/litter	9.5	10.2
Mortality	12.8	7.6
Weights (kg)	--	--
Birth	1.3	1.4
6 weeks	10.5	10.8

English *et al.*, 1977.

Colostrum And Sow Milk

It is very important that piglets get adequate colostrum by nursing the sow the first 24-36 hours. Colostrum is important for protecting the piglets against diseases in the environment. In addition, sow milk is also important from a immunological point of view. Although the immunoglobulins from the sow milk are not absorbed they act in the small intestine and protect the pig from agents in the environment.

Health And Environment

Diarrhea, crushing and starvation are generally regarded as the major direct causes of piglets death. However chilling is probably directly and indirectly responsible for more early deaths than any other factor. It predisposes pigs to crushing, starvation and infection and the weaker the piglet the greater the effect of chilling. The lower critical temperature is 33° C. Below this temperature the piglets must raise its heat production rate to prevent a drop in body temperature. This is possible until the external temperature reaches 10° C. at which stage it drops its body temperature. Once this drop in body temperature starts it may be irreversible and death occurs from exposure. While 10° C. is the extreme situation, cold stress can occur at any temperature above this if the environmental temperature is changed suddenly.

Table 7 shows the preferred temperature for piglets during the first six weeks of life. Conditions at farrowing houses are very important for a high survival rate. The temperature at the farrowing house should be maintained at about

Table 7. Ambient temperature preferred by piglets

Age days	No. of piglets by ambient temperature °C			
	23 - 28	29 - 31	32 - 34	35 - 37
Less than 1	1	2	5	2
1-7	8	16	4	0
7-41	16	33	11	6

Mount, 1963.

Table 8. Influence of attended farrowing on mortality

	No. of pigs born	Perinatal mortality %	Stillborn %	Undersized %
None	8,949	13.7	6.4	1.5
At daytime	4,059	12.9	5.4	1.9
All time	7,382	10.9	4.5	1.0

Bille *et al.*, 1974.

Table 9. Influence of housing of sows in gestation on piglet mortality during perinatal period

	Loose in pens	Fixed in crates
No. of litters	95	116
Birth length (h)		
Pigs	4.6	7.2
Pigs and placenta	7.3	10.0
No. of pigs at birth	11.0	11.4
No. of liveborn pigs	10.2	10.4
Mortality % (0-3 days)	12.6	15.0

Svendsen and Andreasson, 1980.

20° C. and extra heat should be provided for the piglets. By attending sows at farrowing piglets can be saved as shown in Table 8.

It has been found by Svendsen & Andreasson (1980) that sows fixed in crates during gestation have a longer farrowing period than loose sows and this resulted in a higher number of stillborn pigs (Table 9). However, no differences were observed between sows in years, in stalls or tethered in a comprehensive British study (Table 10). It is however, very important that sows in yards are fed individually otherwise the big sows will eat too much and the small ones will not get a sufficient intake.

Table 10. A comparison of three housing systems for pregnant sows

System	No. Farms	Average Farrowing rate (%)	Average Born Alive	Average Born Dead
Yards with individual feeders	11	84.7	10.7	0.74
Stalls	15	85.5	10.4	0.91
Tethers	25	88.1	10.6	0.76

MLC survey, 1976.

Feeding

The sow must be well fed and in good condition, but the sow must not be fat. It should be remembered that all vitamins are easily transferred from sows feed into sows milk, whereas this is not true for all the minerals. Thus it is necessary to provide piglets with iron within the first week of life. Supplemental feeding of small weak pigs will improve livability. Hogberg (1979) found that feeding during the first day after birth of a milk replacer could reduce mortality as supplemental nutrients improve livability for weak pigs as starvation is one of the major causes of death in pigs of low birth weight.

Cross-breeding

An effective method to increase the number of pigs per sow per year is cross-breeding. This is partly due to fewer embryonic losses, and thus a higher number born, but also due to more uniform pigs and therefore a higher survival rate. Table 11 shows results from crossbreeding between Landrace and Large White and Table 12 shows the advantage of three breed cross over two breeds.

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Table 11. Cross-breeding between Landrace and Large White

Combination	L x L	L x LW	L(LW) x L
No. of pigs at birth	10.3	10.7	11.7
No. of pigs at 8 wks	8.2	9.5	9.6
Mortality percent	20.4	11.2	18.8
Weight at birth, kg	1.48	1.53	1.34
Weight at 8 wks, kg	16.1	17.0	16.1

Jensen, 1975.

Table 12. Effect of crossbreeding on pig mortality

	2-breed cross	3-breed cross
Litter site at birth	9.3	10.2
Litter site at weaning	7.1	8.3
Mortality, %	23.7	18.8

Johnson, 1977.

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Management and Nutrition of the Newly Weaned Pig

FRANK X. AHERNE

Our increased knowledge of the nutrient requirements and environmental needs of the young pig together with the incentive to improve the efficiency and profitability of swine production has stimulated a move to earlier weaning. The potential advantages of weaning pigs at 4 weeks rather than 6 or 7 weeks of age are:

1. improved productivity of the sow,
2. reduced sow feed costs, and
3. improved performance of the piglets.

There are therefore potential advantages to weaning pigs earlier than 6 to 7 weeks of age, but there are also potential dangers. It is the balance between these potential advantages and dangers that directs the decision of any producer in his choice of age at weaning.

Currently the average age at weaning in the U.S. is 6 weeks. Data from several sources suggest that in conventional nurseries post-weaning mortality averages about 4.5% varying (1.5-10%) with pigs reaching weights of 29 lbs. or 35 lbs. at 8 or 9 weeks of age, respectively (Washam 1979). These statistics indicate that there are major problems in weaner production. According to English (1976) solutions to these problems may not be applied because:

1. the stockman is unaware that a problem exists or may have no time to apply solutions.
2. the stockman considers the problem not worth solving or that the effort to solve the problem is not cost effective.

Successful weaning starts before weaning with:

1. A sound breeding and feeding programme with the gestating sow to ensure large, healthy pigs at birth. There is a high positive relationship between birth weight and weight at 56 days of age (Lodge and Elliott, 1979).
2. Good piglet and sow management during lactation to ensure strong, even and healthy pigs at weaning. The stock person must be allowed sufficient time to pay necessary attention to detail of piglet health, environment and nutrition.

A good creep feeding programme:

In order to maximize the growth of suckling pigs and to minimize the growth check at weaning it is common practice to introduce creep feed to the suckling pigs

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from 10 to 14 days after birth. The creep feed is intended to allow the pig to maintain its growth rate after the sows milk yield starts to decline at 3 to 4 weeks after parturition. The percentage of the suckling pigs daily nutrient requirements coming from sow milk or creep feed is shown in Figure 1. At 3 weeks only 5% of the pigs nutrient requirements are being met by creep feed intake whereas at 6 weeks creep feed supplies 50% of the pigs nutrient requirements. Lucas and Lodge (1961) have reported that the amount of feed required daily for maximum growth rate of 3, 4 and 5-week old suckling pigs is 45, 227 and 363 g respectively. In our studies we found that creep feeding pigs that were weaned at 3 weeks of age had no significant effect on weight at weaning or on feed intake or performance after weaning (Table 1). Where pigs weaned at 5 weeks of age had access to sow feed there was no significant difference in weight at weaning of pigs not creep fed or those fed simple semi-complex or complex diets (Table 1). However, with faster growing piglets that had no access to sows feed, creep feeding did significantly influence weight at weaning of pigs weaned at 5 weeks of age (Table 2). Growth and feed utilization after weaning was not influenced by creep feeding.

It is generally suggested that if a creep feeding programme is to be successful feed should be fed fresh on a daily basis and that the ration be palatable. Ingredients that usually increase acceptance of corn-soybean meal diets are oat groats, dried whey, fish meal and fats or oils. An example of an acceptable creep feed is shown in Table 3.

3. Choice of optimum age at weaning to suit your facilities, interest and management skills. Surveys have shown that there are producers weaning pigs at 3 to 4 weeks of age and achieving only 13 or 14 pigs weaned per sow per year whereas there are other producers weaning at 7 to 8 weeks who are weaning 20 or more pigs per sow per year. Thus some producers would be better off to do a good job with 6 week weaning rather than do a poor job of weaning at 3 to 4 weeks.

Post weaning:

The performance of the pig after weaning is determined by their genetic potential and by the management, environment and nutritional conditions to which he is exposed. Management and environment are more often the limiting factors to producing good weaner pigs than are nutrition and genetics. Weaning at any age is stressful for young pigs, but the stress of weaning is obviously greater the earlier the pig is weaned. Three types of stress are experienced by the pig at weaning;

1. Environmental stress
2. Social stress
3. Nutritional stress

ENVIRONMENTAL STRESS

Under environmental stress we can consider such factors as:

- Chilling
- Drafts
- Fluctuations in temperature
- Poor sanitation
- Housing and penning conditions.

Chilling

The young pig is very sensitive to cold. Young pigs weaned at 3 to 5 weeks of age require environmental temperatures of 73 to 80°F. (Table 4). The younger the pig the higher the temperature required and the more stable the temperature should be. Daily variations of more than 5°F (2°C) can cause scours and poor performance. It should also be noted that the temperature at eye level may be 10°F higher than temperature at pig level.

The question of a comfortable environmental for the pigs involves more than temperature alone. The degree of comfort experienced by a pig is affected by air movement (drafts), dampness, feed intake, type of floor, closeness of other pigs, and temperature of walls, ceilings and floor. Therefore we should consider the environmental requirements of the pig in terms of effective environmental temperature which reflects air temperature of walls, floor, ceilings (radiant environmental temperature), air movement and floor type.

Drafts

It is important to keep air movement at the level of the pig as low as possible. A scarcely noticeable air speed of 30 feet per minute will chill a pig as much as a drop of 7°F in air temperatures (Table 5). A draft of 90 feet per minute is common in many pig houses and is equivalent to a drop in temperature of 18°F. It is not surprising therefore that Muehling and Jensen (1961) reported that draft-free pigs grew 6% faster on 26% less feed than did draft exposed pigs. When wall or ceiling temperatures are lower than air temperature, radiant heat loss increases. Table 5 shows the combined effects of air speed and radiant environmental temperature. If air speed was 90 ft/min and the radiant-environmental 5°F lower than air temperature thus the effective environmental temperature would be 19°F below air temperature. Under these conditions one could expect poor growth rates and outbreaks of scouring.

Dampness

Wet concrete floors can also increase chilling of the young pig and can be equivalent to a drop in temperature of 10-15°F. However floor covering on concrete floors is comparable to increasing the room temperature by 7°F (Mount 1975). Huddling with penmates also effectively reduces the pigs heat loss. Increased feed intake lowers the critical temperature because of the larger heat increment of feeding. However the feed intake of pigs at weaning is frequently restricted by the stockman or by the pig itself and therefore the reduced feed intake would also support the need for high environmental temperatures for newly weaned pigs.

Sanitation

The piglets immunity system is not fully developed to handle serious enteric disease challenge until 5 or 6 weeks of age, as measured by immunoglobulin secretory ability of the intestine (Porter 1976). Prior to weaning, maternal immunoglobulin (IgA) in the milk has afforded the piglet protection from enteric disease (Lecce 1975, Porter 1976). The level of immunoglobulins in the milk begins to decline two weeks after farrowing at which time the piglet first acquires the ability to respond to infection by producing its own antibodies. As this defense mechanism is not fully developed by weaning (especially 3 and 4 week weaning) post weaning outbreaks of diarrhea frequently result. It follows therefore that at weaning pigs should be moved to clean, dry, weaner pens. Furthermore every effort must prevent the

introduction of new virulent strains of bacteria from outside sources. These precautions together with a minimization of stress should greatly improve pig performance and reduce the incidence and severity of scours. Use of an all-in all-out system of management has been shown to increase pig performance and reduce the incidence and severity of scours. (Table 6).

Housing

The performance efficiency and ecomomics of different housing and penning systems for early weaned pigs will be discussed later by Dr. R. Friesschen.

SOCIAL STRESS

There is little doubt that the removal of the sow from the litter constitutes a considerable stress on the young pig. This stress is further aggravated by moving the pigs to a new pen and in many cases by mixing different batches of pigs. These stresses alone are probably sufficient to make some pigs vulnerable to illness. Our results with mixing pigs after weaning suggest that mixing litters at weaning does cause a significant reduction in pig performance (Table 7). However this reduction in performance is probably less than would be experienced if litters had to be mixed at a later date.

Whether stress of weaning is reduced by leaving the pigs in the farrowing crate for a few days before moving is debatable. We have found no difference in growth rate during the first week after weaning between pigs moved immediately or those allowed 4 days in the crates. A multiple suckling system in which litters were comingled for 1 to 2 weeks before weaning would probably reduce post weaning fighting but not many units are designed to practice such a programme.

Our recommendations are for 3 square feet per pig of floor area for pigs up to 70 lbs. on solid floors and 2 square feet per pig for pigs on slatted floors. If pigs are crowded they will reduce feed intake and therefore performance will be reduced. There is little information on optimum size groups but some data suggests optimum group size of 10 to 15 pigs per pen. (Table 8). With larger groups growth rate seems to decline and variation within the pen tends to increase.

NUTRIENT REQUIREMENTS

The nutrient requirements of the weaned pig depends upon the age and weight at weaning. Presumably the best guide to the nutrient requirements of the weaned pig are those published by the National Academy of Sciences-National Research Council (NRC). The 1979 recommendations of the NRC are shown in Table 9. For pigs weaned at 5 to 10 kg a 20% protein diet is recommended. Actually, swine do not have a requirement for protein per se but rather for sufficient nitrogen to synthesize the nonessential amino acids and specific amounts of the essential amino acids. However, we frequently formulate starter diets to meet a certain protein content and use protein of high biological value. Using the grain sources and protein supplements most frequently used to formulate starter diets, most recent results suggest that 20% protein is the minimum required for pigs of 5 to 10 kg liveweight at weaning. (Table 10, 11, 12).

Regarding amino acid levels there is evidence accumulating that the 5 to 10 kg pig requires more lysine in the diet than 0.95% (Table 13, 14). These studies suggest that the requirement is at least 1.15%. Thus a corn soybean ration formulated to contain 20% protein would supply the required 1.10% lysine.

NUTRITIONAL STRESS

Nutritional stress at weaning arises primarily due to change to a solid diet from a milk diet. This sudden change from 16 regular meals a day of a highly nutitious and digestibile milk diet to a dry feed diet results in a period in which pigs refuse to eat the feed and then after a 12-16 hour starvation period pigs may eat a large meal (Stevens 1963, Thomlinson 1969). For pigs weaned before 5 weeks of age their digestive enzyme system may not be sufficiently developed to allow proper digestion of cereal based solid food diets (Aumaitre 1972). Thus the intake of a large meal of solid food may overload the digestive system and result in diarrhea. This combination of erratic food intake, diarrhea and incomplete digestion of solid food frequently results in post weaning growth check. This growth check has been described by several workers (Smith and Lucas 1956; 1957, Leibbrandt *et al.* 1975, Okai *et al.* 1976, Rivera *et al.* 1978), and depending on the diet fed and age of pigs weaning may last for 7 to 14 days. (Figure 2). With 3 week weaned pigs recovery to weight at weaning was achieved by pigs fed the complex diet in 3 days, while it took pigs fed the semi-complex and simple diets 6 to 7 days to recover their weaning weights. Thus it is possible to reduce but not eliminate the post weaning growth check of early weaned pigs by using complex starter diets. For pigs weaned at 5 weeks of age growth check is considerably less than that observed with 3 week weaned pigs (Figure 3). In our experiments pigs fed simple semi-complex or complex starter diets all managed to gain weight during the first week post weaning.

Type Of Diet

The composition and complexity of the diet is frequently discussed in relation to post weaning pig performance and occurrence of post weaning diarrhea. Our experimental results with pigs fed diets of different complexity (Table 15) are shown in Table 16. Pigs weaned at 3 weeks of age performed best when fed the complex diet. However, the most economical 7 week weight was obtained with pigs fed the simple starter. For pigs weaned at 5 weeks of age there was no significant difference in performance between pigs fed either of the 3 diets. Meade (1971) concluded from the results of 15 experiments involving 4700 pigs that increasing the complexity of the diet of 3-week weaned pigs generally increased feed intake and growth rate but feed conversion efficiency was not always improved. However rate and efficiency of gain of pigs subsequent to the starter phase were not significantly affected by kind of starter diet. More recently Tanksley (1979) has reported that for pigs weighing less than 15 pounds at weaning, complex diets had significantly better growth rate and feed conversion efficiency than pigs fed simple diets (Table 17). Again the composition of the starter diet did not influence performance during the growing-finishing period. These data lead one to conclude that weight is a better criterion than age as a basis for weaning. Further support for this suggestion is afforded by the work of Zimmerman (1972). In this experiment pigs of less than 10 lbs. at weaning had a better growth rate and feed efficiency when fed diets containing 20% dried skim milk (Table 18). Pigs of 10 lb. weaning weight showed no response to that addition of skim milk to the diet. Our results also demonstrate that weight at weaning also significantly influences the pigs response to diet composition (Table 19). Further support for the suggestion that pigs of 15 lb. do not respond to increased complexity of the diet is presented by Adams and Jensen (1979) (Table 20). An explanation as to why pigs fed complex diets do not out-perform pigs fed simple diets may be related to the incidence of post-weaning scours. The complexity of the starter diet has been suggested to increase the potential for scouring due to the greater palatability of the diet, leading to over consumption (Okai *et al.* 1976, Bayley and Carlson 1970, Smith and Lucas 1956). In contrast the poorer consumption of the simple diets has been

shown to result in lower incidence of diarrhea. (Table 21). This may explain the reduced superiority of complex diets over simple diets.

The ideas of English (1979) on the feeding of the newly weaned pig are worthy of consideration. English suggests that ad libitum feeding of newly weaned pigs might be possible if one had an early weaning diet of sufficiently high digestibility that there was minimum risk of digestive upsets and scouring with such a diet fed ad libitum. This high digestibility diet was based on milk by-products, vegetable oil and cooked cereal (Table 22). When the diet was compared with two commercially available diets for pigs weaned at 17 to 21 days on both ad libitum (AL) and restricted (R) feeding systems the incidence of scouring was as indicated in Figure 4. It can be seen that there was a higher incidence of scouring on the ad libitum than on the restricted feeding system except in the case of the highly digestible diet. When this HD diet was tested with 703 pigs on a commercial farm using pigs weaned at 17 to 21 days average daily gain, feed-gain ratio and percent mortality for the first two weeks after weaning were 189 grams, 0.95 and 0.14% respectively. These milk based complex diets can also be used to raise orphan pigs or under-privileged pigs in larger litters. If such pigs are allowed to continue with the sow they will die or develop into runts. Such pigs can be raised successfully if a suitable environment and cage system are made available and they are provided with complex milk based diets.

Restricted Or Ad Libitum Feeding

If volume of feed intake is an important factor in causing post weaning scours, then restricting feed intake should reduce the incidence and severity of diarrhea. Arambawela *et al.* (1975) reported a higher incidence of digestive disturbances in 3 week weaned pigs fed ad libitum. Restricting feed intake reduced the counts of total and of hemolytic E.Coli per g feces in early weaned pigs in the experiments of Palmer and Hulland (1965). In several experiments we have also demonstrated that the incidence and severity of diarrhea is lower with restricted fed pigs but the performance of pigs fed ad libitum is nevertheless superior. (Table 23).

On the basis of our experience we do not recommend restricted feeding of early weaned pigs.

Dietary Fiber Level

Increasing the level of fiber in starter pig diets has received much attention of late. Though sources of fiber such as cellulose and solka-floc, have been tried (Corley *et al.* 1978) most of the recent studies have been directed towards the use of oats in pig starter diets to increase fiber level. The majority of the published papers report performance similar to that shown in Tables 24, 25. The results of several other studies also suggest that the addition of oats to starter diets does not improve the growth rate of starter pigs nor does it have a significant effect on visual diarrhea score. (Rivera *et al.* 1978, Watts and Moser 1979, Wahlstrom *et al.* 1977, Armstrong and Cline 1976, 1977.) However in a recent study Tanksley (1979) did report an improvement in growth and feed conversion efficiency of pigs fed a diet containing 10% oats (Table 26).

High Nutrient Density Diets

Maintenance of rapid growth rate during the post weaning period requires a high energy starter diet to replace sow milk. High energy starter diets can be

achieved by the addition of fat to the diet. Conflicting opinions exist as to the value of fat in the diet of young pigs. The reasons for these conflicting views may be the result of the method by which fat is added to the diet. Several studies have shown that when fat replaced carbohydrate in starter pig diets, with no upward adjustment made in protein, vitamin or mineral level of the diet, young pigs (3-5 weeks of age) did not utilize fat efficiently (Frobish 1969, 1970). In such cases fat supplementation did not improve pig performance. However our results (Tables 27, 28) and those of Allee *et al.* (1971) demonstrate that when nutrient-calorie ratio is maintained constant the addition of fat to pig starter diets will improve average daily gain and feed conversion efficiency.

Feed Additives To Starter Diets

Most starter diets contain some antibiotic or other antimicrobial compound. A recent survey of the effects of antibacterials in starter diets by Hays and Muir (1979) is summarized in Table 28a. It can be seen that over a wide range of test conditions the improvement in growth and feed efficiency resulting from the addition of antibacterial compounds to starter diets is very impressive. Antibiotics perform differently on every farm and the response to a particular antibacterial agent may change with time. Producers are advised to have periodic sensitivity tests performed by the veterinarian so that they will have an effective antibiotic on hand should a problem of scouring arise.

In recent years concern over bacterial resistance to antibiotics has prompted experimentation with other compounds that might prevent or reduce disease problems and improve the performance of young pigs. One such approach has been the addition of bacterial cultures to starter diets. Lactobacillus Acidophilus has been used most frequently. It is thought that these bacteria would produce lactic acid in the intestine and the acidity would be increased in the intestine to the point where growth of potentially harmful organisms such as E. Coli would be reduced. In general the addition of lactobacilli to the diet has not improved pig performance or reduced the incidence or severity of post weaning scours. (Table 29, 30).

FEEDING SYSTEMS

Since young pigs are accustomed to eating at the same time, enough feeder space (3-4 inches per pig) or floor feeding is frequently recommended to take advantage of the pigs natural instinct. In a recent trial we compared floor feeding and different feeder space allowances per pig for pigs weaned at 4 weeks of age. There was no significant influence of method of feeding during the first week post weaning or growth rate over a 4 week period. (Table 31). Floor feeding during the first week led to considerable feed wastage.

Some feed wastage is inevitable but it should be cut to a minimum. In the trials in which feed wastage has been closely observed it has been reported that pigs waste 10 to 15% of the feed fed. Feeders with feeder holes, easily adjustable feed plates and lips to prevent feed flowing over the front edge of the feeder can reduce feed wastage to a considerable degree. In many swine units the reduction in feed conversion efficiency resulting from feed wastage can offset any increased profit potential from extra pigs raised (Table 32). In this example 16 pigs per sow per year with good feed efficiency are as profitable as raising 17 pigs per sow with a poorer feed conversion rate. Pelleting of the feed generally leads to about a 5% improvement in feed conversion efficiency, probably more from a reduction in feed wastage than any improvement in the nutritional value of the feed (Table 33).

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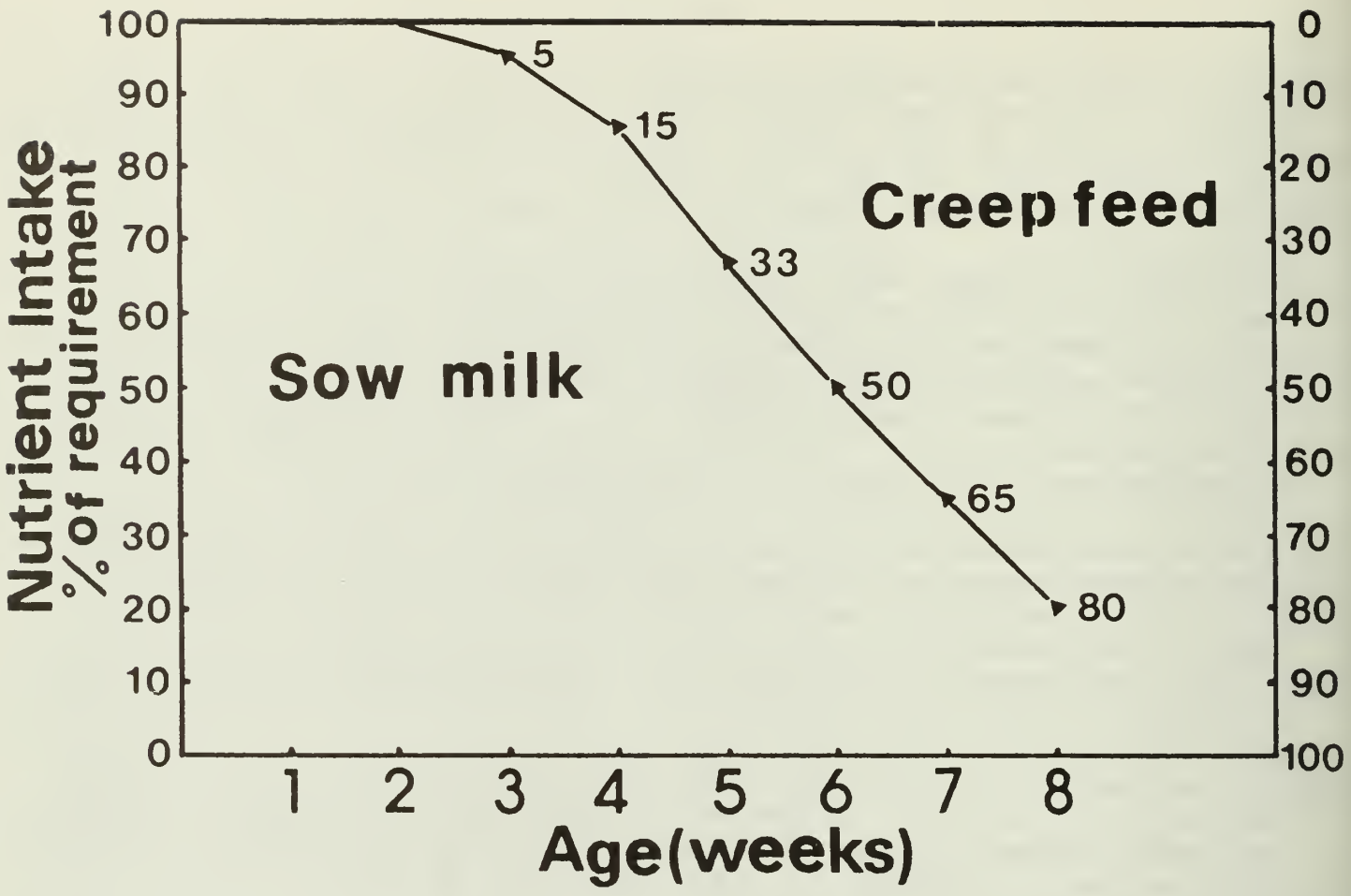

Figure 1. Relative intake of milk and creep feed for suckling pigs.

Table 1. Effects of creep feeding on weaning wt. (kg)

Treatment and Age at Weaning	No Creep	Simple	Semi-Complex	Complex
3 weeks	5.1	4.8	4.9	4.9
Daily feed (g/pig)	0	1.2	2.1	6.5
5 weeks	7.1	7.0	7.3	7.5
Daily feed (g/pig)	0	22.3	41.7	66.0

Univ. of Alberta, 1976.

Table 2. Performance of pigs creep fed or not creep fed before weaning

Group	Creep fed	Not creep fed
Avg. weight, kg		
2 weeks	4.3	4.3
5 weeks	9.4	8.6
Avg. daily gain (g)		
2-5 weeks	244	206
5-8 weeks	344	340
Hb %		
2 weeks	11.0	10.9
5 weeks	9.6	8.7

Aherne *et al.*, 1980.

Table 3. Composition of creep feed

Corn	56.5
Soybean meal	23.1
Fishmeal	5.0
Dried Whey	10.0
Corn oil	3.0
Dical. phosph.	1.0
Grd. limestone	0.6
Vit.-Min. mix	0.55
ASP-250	0.25
Analysis	
Dig. Energy kcal/kg	3400
Protein %	20
Lysine %	1.2
Calcium	1.1
Phosphorus	0.8

Table 4. Temperature requirements

Age of weaner	Temperature required at pig level
3 weeks	80°F
4 weeks	76°F
5 weeks	73°F

Table 5. Calculating effective environmental temperature

Air speed ft./min.	Difference between air temperature Radiant - Environmental Temperature (F^{o}) 0	5	10	15
0	0	-4	-9	-13
30	-7	-11	-14	-17
60	-13	-15	-18	-20
90	-18	-19	-21	-23

Mount, 1975.

Table 6. Continuous vs all-in-all-out housing on pig performance of 3 week weaned pigs

Management system	Continuous	all-in-all-out
Avg. daily g	400	503
Feed/gain	1.89	1.74

Le Dividich and Aumaitre, 1978.

Table 7. Effects of mixing pigs at weaning

Days after weaning		Weight of pigs Less than 5.0 kg	Greater than 5.0 kg
0	Mixed	4.3	6.1
	Not mixed	4.4	5.9
0	Mixed	7.7	10.4
	Not mixed	8.9	11.2

Aherne, 1979.

Table 8. Effects of stocking density and surface area on performance of weaned pigs

Number pig/pen	8	16	24
Surface area/pig m^2	0.3	0.3	0.3
Avg. daily gain (g)	430	420	400
Feed/gain	2.14	2.24	2.18

Le Dividich and Aumaitre, 1978.

Table 9. Nutrient requirements of starter pigs

Liveweight, kg	5-10	10-20
Digestible energy kcal/kg	3500	3370
Crude protein, %	20	18
Lysine %	0.95	0.79
Threonine %	0.56	0.51
Tryptophan %	0.15	0.13
Methionine + Cystine %	0.56	0.51
Calcium	0.80	0.65
Phosphorus	0.60	0.55

NRC, 1979.

Table 10. Effects of dietary protein level

% protein	21	19	17
Avg daily gain, kg	0.37	0.36	0.29
Avg daily feed, kg	0.59	0.60	0.58
Feed:gain	1.59	1.67	1.99

259 pigs/trt initial wt 7.0 kg, 4 week trial.
Adams and Jensen, 1979.

Table 11. Level of protein in barley wheat rations fed to pigs weaned at four weeks[a]

	Percent Protein		
	22	20	18
Daily gain, kg	0.33	0.34	0.32
Feed/gain, kg/kg	1.96	1.93	2.33

[a]32 pigs per ration averaging 7.2 kg (15.9 lb).
Newman and Sharp, 1968.

Table 12. Effect of protein level of performance of pigs weaned at 4 weeks of age[a]

	18	20
Initial weight	15.4	15.3
Entire test (42 days)		
Avg daily intake	1.79	1.79
Avg daily gain	0.86	0.93
Feed/gain	2.08	1.92
Final weight	51.1	54.4

[a]128 pigs/treatment (16 pens, 8 pigs/pen). All wts expressed in lbs.
Tanksley, 1979.

Table 13. Effects of lysine levels on baby pig performance

	Dietary lysine level %		
	0.95	1.05	1.15
ADG, lb	0.60	0.57	0.58
ADF, lb	0.99	0.90	0.88
Gain:feed	0.60	0.63	0.65

Zimmerman, 1979.

Table 14. Performance of pigs fed different lysine levels

	Lysine level %					
	0.95	1.05	1.15	1.25	1.35	1.45
ADF, lb	1.34	1.42	1.50	1.57	1.44	1.43
ADG, lb	0.71	0.77	0.81	0.88	0.79	0.79
Feed/gain	1.96	1.86	1.83	1.79	1.86	1.82

Lewis, 1980.

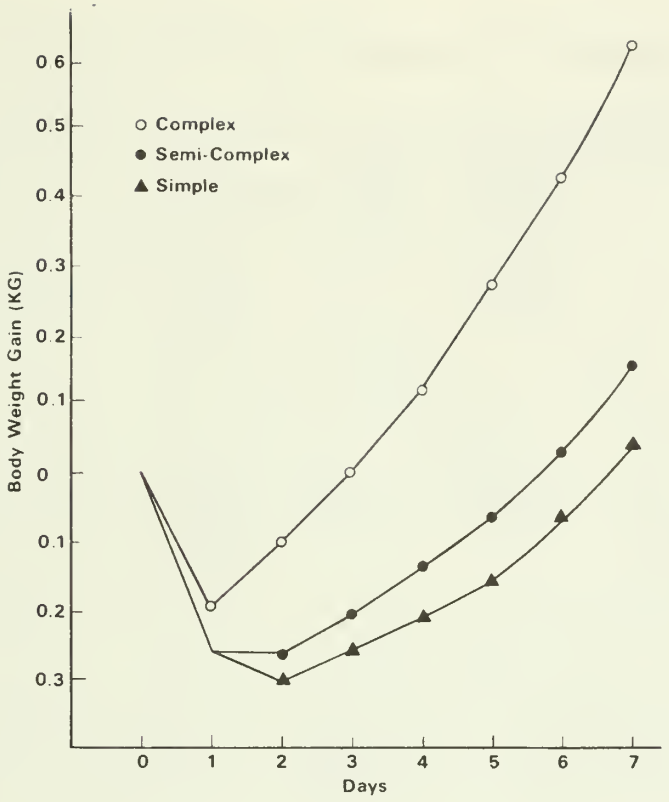

Figure 2. Post weaning check in pigs weaned at 3 weeks.

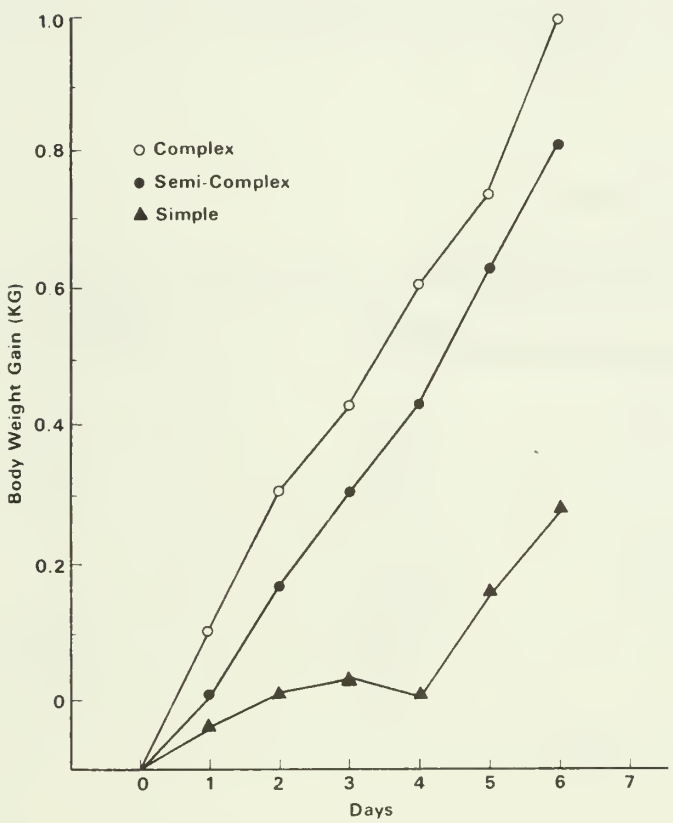

Figure 3. Post weaning check in pigs weaned at 5 weeks.

Table 15. Composition of starter diets

Ingredients	Simple	Semi-Complex	Complex
Wheat	45.0	25.0	--
Barley	13.5	15.0	--
Oat groats		25.0	--
Dextrose			10.0
Sucrose			9.0
Corn starch			17.5
Tallow	3.0	2.0	1.0
SBM	34.0	13.0	13.0
Herring meal		6.4	11.0
Dried skim milk		10.0	20.0
Dried whey			15.0
Vit-min mix	4.5	3.6	3.5

Table 16. Effects of starter diets

	Simple	Semi-Complex	Complex
Weaning wt (3 wks) kg	5.1	5.2	5.0
7 wk wt kg	12.6[a]	13.7[b]	14.5[b]
ADG kg	0.27[a]	0.31[b]	0.34[c]
G/F	0.61	0.64	0.63
Weaning wt (5 wks) kg	7.4	7.1	7.5
8 wk wt kg	13.4	13.5	14.3
ADG kg	0.29	0.31	0.33
G/F	0.60	0.63	0.63

University of Alberta, 1976.

Table 17. Effect of protein source (simple vs complex) in starter diets on pig performance from weaning to market[a]

	Protein source[b]	
	Simple	Complex
Initial weight lb	13.0	13.0
First 35 days postweaning[c]		
Avg daily intake lb	1.28	1.35
Avg daily gain lb	0.61	0.68*
Feed/gain	2.13	2.00**
Weight after 35 days	34.2	36.8
35 days to market[c]		
Avg daily intake lb	5.34	5.41
Avg daily gain lb	1.54	1.55
Feed/gain	3.47	3.48
Marked weight lb	213.1	213.0
Days in G-F phase	116.6	113.7

[a]Means represent 160 pigs.
[b]Soybean meal was the only supplementary protein source in Simple diets; Complex diets contained 5% fish meal, 10% dried whole whey and 10% ground oats in addition to soybean meal.
[c]All pigs received a 16% sorghum-soybean meal diet until they averaged about 120 pounds; then a 14% diet until market weight.
Tanksley, 1979.

Table 18. Weaning weight and response to dried skim milk

Weaning wt, lb	6.5	6.5	10	10
Dried skim milk, %	0	20	0	20
4-week gain, lb	14.7	16.3	18.5	18.7
Feed:gain	1.7	1.5	1.6	1.6

Iowa State Univ., 1972.

Table 19. Effect of weaning weight on response to diet composition

Diet Daily gain, kg	Simple	Semi-Complex	Complex
Heavy pigs	0.34	0.35	0.35
Light pigs	0.24	0.27	0.30

Okai *et al.*, 1976.

Table 20. Simple vs Complex diets

	Diet	
	Simple	Complex
Avg. daily gain, kg	0.36	0.36
Avg. daily feed, kg	0.635	0.631
Feed:gain	1.76	1.75

192 pigs/trt, initial wt 7 kg--4 week trial.
Adams and Jensen, 1979.

Table 21. Incidence of scours at weaning (days)

	Trial 1		Trial 2	
Diet	Simple	Complex	Simple	Complex
Ad libitum	32	49	71	79
Restricted	11	32	42	54

Ball and Aherne, 1979.

Table 22. A highly digestible diet for early weaned pigs

	%
Breakfast oat flakes	34
Spray dried skim milk	10
Denatured skim milk	14
Piglet milk substitute (20% tallow)	25
Corn oil	10
Glucose	5
Vit-min mix	2

P. English, 1979.

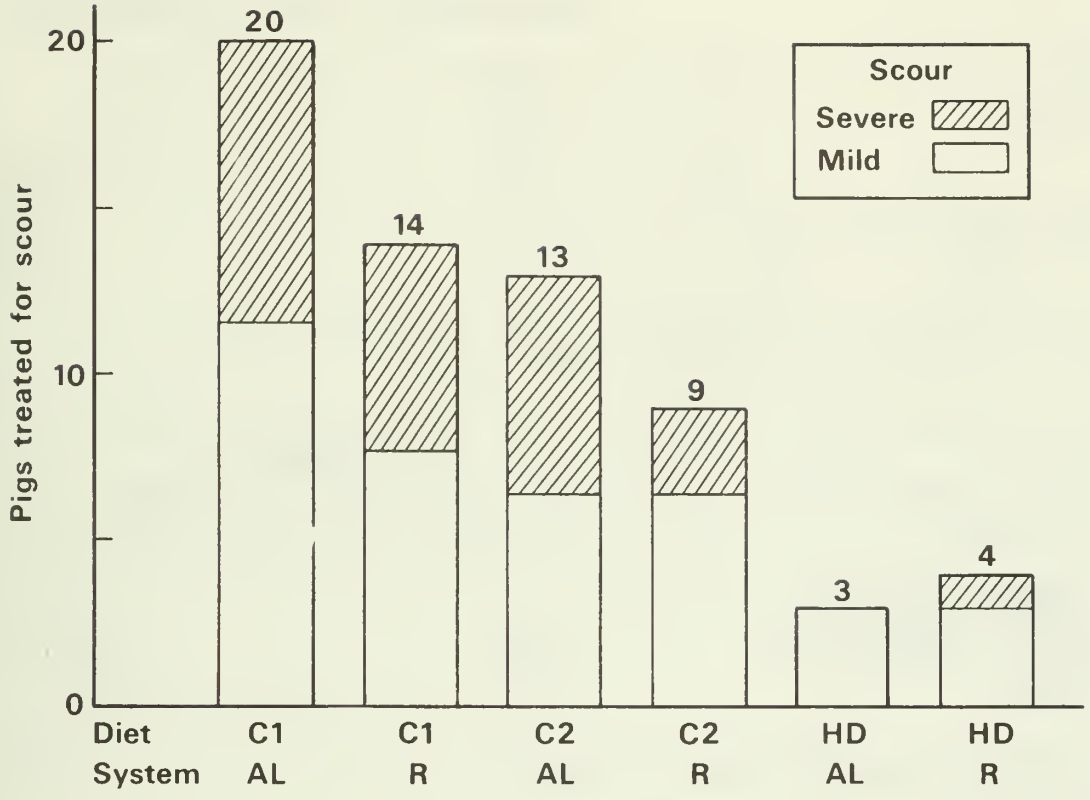

Figure 4. Veterinary treatments for scour.

Table 23. Effects of feed intake on 3 week weaned pigs

	Ad Lib	Restricted (88%)
Daily feed g	389	302
Daily gain g	225	181
Feed/gain	1.74	1.68
Scour		
Intensity	162	102
Incidence	71	42

Ball and Aherne, 1979.

Table 24. Effect of rolled oats on young growing pig performance[a]

Treatment	Control	Rolled Oats 15%
No. pigs[b]	144	144
Daily gain, lb	0.76	0.75
Daily feed, lb	1.56	1.54
Feed/gain	2.07	2.06

[a]Mahan and Newland, 1976.
[b]Four week old pigs weighing initially 17. + lb. fed for six weeks to about 49 lb.

Table 25. Copper and oat additions to starter diets (4-6 weaned pigs)

	Control (C)	C + 20% Oats
ADF/kg	0.54	0.55
ADG (kg/day)	0.29	0.30
F/G	1.86	1.83

Arthur *et al.*, 1979.

Table 26. Effect of including 10% oats in starter diets for pigs weaned at 4 weeks of age[a]

	Percentage Oats	
	0	10
Initial weight	15.4	15.2
Entire test (42 days)		
Avg daily intake lb	1.80	1.78
Avg daily gain lb	0.88	0.91*
Feed/gain	2.05	1.96

[a]128 pigs/treatment (16 pens, 8 pigs/pen).
Tanksley, 1979.

Table 27. Formulation and composition of diets

Diet	1	2	3	4
Barley	34.0	22.1	30.0	29.7
Wheat	34.0	22.1	24.0	24.0
Soybean meal	6.1	14.7	10.1	10.1
Fish meal	5.0	6.2	5.0	5.0
Skim milk powder	10.0	12.3	10.0	10.0
Dried yeast	5.0	6.2	5.0	5.0
Sugar	3.0	3.0	3.0	3.0
Lard	--	10.0	--	10.0
Starch	--	--	10.0	--
Calcium carbonate	0.5	0.6	0.5	0.5
Dicalcium phosphate	1.5	1.7	1.5	1.8
Iodized salt	0.3	0.4	0.3	0.3
Vitamin-mineral premix	0.6	0.7	0.6	0.6
Composition, calculated				
Crude protein %	20.0	23.4	20.2	20.1
Digestible energy (DE) kcal/kg	3480	3998	3506	3946
Protein:Calorie ratio (g protein/mcal DE)	57.4	58.4	57.6	51.1
Ether extract %	2.2	12.8	1.9	12.9

Aherne *et al.*, 1980.

Table 28. Fat utilization by weaned pigs

Diet	1	2	3	4
Daily feed, g	657	694	704	629
Daily gain, g	333	435	357	325
Feed/gain	1.99	1.60	1.99	1.94
Feces score	0.17	0.10	0.18	0.16
mcal DE/kg gain	10.5	9.2	9.8	12.2

Aherne *et al.*, 1980.

Table 28a. Response of pigs to antibacterials (starter stage, initial weight less than 16 kg)

Antibacterial	Reps.	% improvement	
		Daily gain	Feed/gain
Tetracycline-sulfamethazine penicillin+	333	22.5	8.5
Mecadox	292	18.6	8.6
Tylosin-sulfamethazine	76	17.6	6.8
Penicillin-streptomycin	95	14.8	7.4
Tylosin	124	14.8	6.0
Lincomycin	8	11.1	7.6
Virginiamycin	90	11.0	5.0
Tetracycline	234	10.8	6.2
Bacitracin	54	9.7	3.3
Penicillin	14	9.4	8.7
Nitrofurans	66	8.0	2.3

+Also includes tetracycline and penicillin in combination with sulfathiazole. Hays and Muir, *CJAS* 59:447 (1979).

Table 29. Effect of Probiotic on piglet performance

Treatment	Control	Probiotic (0.15%)
No. pigs	144	144
Daily gain lb	0.76	0.74
Daily feed lb	1.56	1.55
Feed/gain	2.07	2.10

Mahan and Newland, 1976.

Table 30. Effects of Lactobacillus added to starter diets

	Control	Lactobacillus acidophilus [a]
Av. initial wt kg	5.8	5.8
Av. 9 wk wt kg	18.8	18.3
Feed/gain	2.40	2.36
No scour treatments	43	41

[a]Contained 100 million active bacteria per ml.
Nielsen *et al.*, 1976.

Table 31. Evaluation of trough space and floor feeding for 4 week weaned pigs

	Floor feeding	1 pig/ feeder hole[a]	2 pigs/ feeder hole[a]
Avg. initial wt kg	5.96	5.94	5.90
Avg. final wt kg	11.10	11.41	11.39
Daily gain (g)			
First week	47	49	38
Four weeks	184	196	196
Daily feed (g)	378	376	357
Feed:gain	2.06	1.92	1.82

[a]All pigs assigned to 2 pigs/feeder hole after first week
10 pigs/pen.
Aherne and Jensen, 1980.

Table 32. Pigs fed from 5 to 25 kg liveweight

20 kg gain @ 1.7 = 34 kg feed

20 kg gain @ 2.0 = 40 kg feed

34 kg feed for 16 pigs
40 kg feed for 17 pigs

40 x 17 = 680 kg	34 x 16 = 544 kg
@ 22¢	@ 22¢
= $150	= $120

Table 33. 30 comparisons of meal vs pelleted diets

	Meal	Pellet	Effect of Diets %
Daily gain, lb	1.61	1.71	+6.2
Daily feed, lb	5.67	5.74	+1.2
Gain, per ton, lb	568	596	+4.9

Housing for the Newly Weaned Pig

ROBERT D. FRITSCHEN

Housing requirements for the weaned pig (nursery) are not well defined relative to other phases of the life cycle. Too, at no other stage of the life cycle are biological and nonbiological variables more critical to the pigs well-being and survival. It is difficult to explain why this critical, sensitive period in the animal's life has not received the research attention which, hopefully, would result in sound housing alternatives. Perhaps part of the reason is cost. But more likely, the reasons relate to the great range in response to small management variations. The inability to transpose research findings to production situations with acceptable consistency is at the heart of the matter. Therefore, what we "know" is based upon field observations blended with European literature and a paucity of domestic research.

The nursery has two separate but related components that must be considered. The first is the pen itself. Dimension, arrangement, size and material are part of the pen component. All must be in harmony with each other and the pig. The second component is the building. While important, the building in reality plays a support role in the total picture.

THE PEN

The modern floor level pen has evolved to a space that often contains 20 to 24 pigs. Fewer pigs per pen may be ideal from a pig performance basis, but not necessarily so on a building-equipment cost basis. The weight going in and coming out of the nursery pen will dictate space allocations. Allotting space at the rate of 1.7 to 2.5 square feet per pig from 15 to 40 pounds is common. For purposes of discussion, two square feet will be used, which represents a compromise between initial and end point space requirements.

The amount of slotted floor will determine to some degree the pen shape. When a pen is partially slotted it should be rectangular in shape. For example, a pen that is 10 feet X 3.5 feet will provide 35 square feet, which would allow 20 pigs 1.75 square feet. With this amount of space, the pen would typically be vacated when the pigs weighed 30 to 35 pounds. A pen that has a solid or partially slotted floor requires a rectangular pen to control dunging patterns. It is generally conceded that the more square the pen, the greater the risk of messy pens.

The environmental objectives within the pen include reducing drafts and controlling the temperatures. As a result, solid pen partitions are advised. The possible exception is where the slotted portion of the floor is at the opposite end from the sleeping area. In this case, a mesh or pipe pen divider over the slotted area on one or both sides of the pen is used.

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Floors that have a solid sleeping section in the middle of the pens with in-floor heat, and slats at either end have been shown to work well. Since the pig seeks a corner for dunging, this reduces the risk of messy floors that is sometimes associated with other partially slotted floor arrangements. Having solid floor on both ends of the pen and a slotted center area nearly always results in messy pens and should be avoided.

The use of hovers to prevent drafts seems to have more success in field use than under research conditions. Hovers, to be effective in a nursery pen, should be lower at the rear of the sleeping area with an elevation of 14 to 18 inches, depending on the size of the pigs. The hover material should fit tightly at the sides and rear so that drafts cannot enter the sleeping area, and also to prevent heat loss. Properly designed hovers may be installed in such a manner so that they may be easily adjusted for elevation or removed for cleaning.

Some producers have elected to use a semisolid waste system that includes bedding. Dry bedding is very desirable for pig well-being, but has the disadvantage of being part of a more labor intensive system. When bedding is used in a solid floored nursery, it is critical that a bedding board such as 2" X 6" or 2" X 8" be placed on edge to retain the bedding in the sleeping area. The bedding board should be fixed in such a way that it may be moved forward as more sleeping area is required. Dry bedding properly managed with a bedding board in conjunction with a hover establishes an environment that in many cases requires very little supplemental heat.

The trend toward, and the alleged economic rewards associated with three week weaning, have resulted in the need for a much improved nursery pen. In the past five years, the proliferation in use of cages, stacked cages and flat decks has been an expression of that need. Studies and field experience have again been variable, but generally the evidence favors their use. The popular European press has concluded that the flat decks will eventually be shown to be the most beneficial. Even so, the double decks are conceded to be the most current popular arrangement of this concept. The reason is perhaps due to the additive effect of greater warmth (off the concrete), less draft and improved sanitation, as compared to floor level pens.

Decks and cages, when farm constructed, often have partial solid floor, usually made from wood (other than plywood). They may have some solid pen divider as well, for draft control. Brand name decks or cages usually are made entirely of metal.

Some of the advantages attributed to flat decks or cages are:

- Ideal for early weaning
- Small pens
- Convenient for small group sizing
- Increased ADG
- Reduced F/G
- Reduced mortality
- Easier observation
- Easy to clean
- More efficient space utilization (double decks)
- Use of existing building with minimum renovation

Disadvantages of cages may be:

- Initial cost
- More labor
- Difficult sanitation
- Lack of a system
- Observation more difficult (double decks)
- Variable control of waste matter

There is little doubt remaining concerning the utility of decks and cages. They do have the capability of more nearly providing the required environment, and they have their greatest potential where early weaning is practiced.

THE BUILDING

While nursery or weaning buildings are available on the market, the fact remains that the building itself is but a shell which provides the basis for organizing pens and equipment in such a manner that the environment will support a high level of productivity for a given phase of the life cycle. As a consequence, many existing farm buildings could be considered for renovation for nurseries. It should be emphasized that the great need for controlling certain components of the environment are not being compromised when statements about renovating existing buildings for nursery use are made.

Designs for nurseries are available from various Cooperative Extension Services and from the Midwest Plan Service office in Des Moines, Iowa. Midwest Plan Service is supported by various Universities in the North Central Region, and as a consequence, their plans and publications are usually available at local Extension offices.

An additional item that does not appear on most plans is the use of 4 or 6 mil vapor barrier under the concrete floor. This is especially important where floor level pens are used, but is still cost effective where decks or cages are used. The vapor barrier under the concrete floor prevents the movement of moisture from the soil through the concrete where it would otherwise evaporate at pig-floor interface, thereby chilling the pig.

In a building with floor level pens, zone warming of the pig area should be considered a requirement. Since a pig weaned at three to four weeks of age requires a temperature of 80 to 85° F, it is impractical to heat the entire room to that level. Therefore, it is common practice to zone heat to a temperature of 80 to 85° F, and keep the room temperature in a range of 72 to 76° F. The buildings with decks or cages are often heated only with heaters or furnaces with no zonal heating. This is especially true with double decks. It should be recognized that the heating requirements of pigs on the lower deck may be greater than those in the upper deck near the ceiling. As a consequence, if there is a difference in pig size, the larger pigs should be located in the lower deck with the smaller ones going in the upper deck.

The need for care in the quantity, quality and installation of insulation in a nursery cannot be overemphasized. Rodent control must be a concern when installing insulation as recent history indicates that mice and rats may destroy insulation where it is not adequately protected.

Ventilation design and management are especially critical since we often tend to over ventilate nurseries. The ventilation system should be capable of providing one complete air change every 10 minutes with a range of 2-30 CFM's per pig. The typical slot air inlet needs to be modified for winter use so that incoming air is tempered and deflected. This is particularly important in double deck arrangements. A possible solution has been used in Canada, and elsewhere with success, where they utilize a small room to temper the incoming air before it enters the pig area. To utilize the attic for this purpose is also a good practice in winter, but it has never fully caught on because a winter and summer inlet system is required. A small air tempering room is effective to that end regardless of season.

SUMMARY

Weaning in the Midwest takes place over a wide range of age with variations of from two to six to seven weeks. This makes it difficult to standardize recommendations for housing or management. More typically, pigs are weaned at three to five weeks. The pig at this age is highly vulnerable to stress and disease since its immunity system is only beginning to function. It appears that all of nature is against the pig at this point in its life. Many management factors such as, all in - all out, draft control, dry floors, scour prevention, etc., have been mentione so often as to become nearly trite. Yet, they are the very heart and soul of success. In working with producers who have nursery problems, and they are nearly legion, most cases involve suboptimum temperature, drafts and over ventilation.

It is a fact that a common recommendation cannot be made for a nursery. Also, it is a fact that nearly any nursery will function successfully when matched up with appropriate management. Since many individuals think of a nursery as an area or space, no general building type has evolved as being most popular. Flat decks and double decks have the advantage of raising the pig from the floor and placing him in a potentially warmer, drier and draft free zone.

Finally, bedding no longer has the image of wet floors and health hazards for many producers. Consequently, for many, especially small or medium volume producers, well managed bedding is a part of their nursery system.

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Welfare of Animals in Animal Science Research

STANLEY E. CURTIS

Today's world is a hungry place, a situation complicated by the fact that the number of people who can grow their own food is dwindling. "Next to food, what the world needs most is someone who knows how to grow it."

It should go without saying, but unfortunately in this age when less than 4 percent of the population feeds the other 96 percent, the vast majority of this country's citizens have never set foot on a farm or cultivated or harvested one mouthful of their daily bread, so it must be said: This nation's farmland and agricultural industry are this nation's ultimate resource. By increasing agricultural productivity decade after decade, farmers and the scientific organizations and business firms which support their industry have proved time and again to be trustworthy stewards of the precious, renewable resource. They also have demonstrated that they "know how to grow it." Our agriculture is the marvel of the world, an asset that will be treasured by all mankind even more in the future than it has been in the past. But make no mistake about this: the challenge to increase agricultural productivity in step with future demands is a huge one. Feeding the masses of this country and of the world is perhaps the most honorable thing one man can do for his fellowman.

PORK PRODUCTION: AN HONORABLE BUSINESS

Pork production is a significant segment of agriculture here. It is a most honorable vocation. And when ethical vegetarians impugn the fundamental motive of pork producers, they at once lay bare their own arrogance and their own naivete and their own narrowmindedness. The fact is, notwithstanding the urgings of a handful of vocal activists who would dictate their own tastes and ethics on the rest of us, many of the people of this world will devour with considerable relish every bite of pork the world's producers can serve up in the foreseeable future. None will spoil. None will go to waste. At the same time, those who prefer bean sandwiches and pulse curds--and are able to balance their diets only because of the knowledge resulting from nutritional experiments on animals--should feel free to feed on these nutriments with abandon; that is, until some-

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[1]Prepared for presentation before the Animal Welfare Committee of the U. S. Animal Health Association at Louisville, Kentucky, on 4 November 1980. The author gratefully acknowledges the contributions of John J. McGlone, Gerald L. Morris, and Debra L. Wende to this report.

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one decides legumes have the same rights as animals, trees, and rocks.

Still, most people on this earth like some bacon with their eggs in the morning, some ham with their beans at lunchtime, a pork chop or bratwurst with their potatoes and Brussels sprouts for dinner. Pork production is a business--a most honorable business--simply because there are hundreds of millions of humans who eagerly follow the centuries-old tradition of clearly preferring to have pork in their diets, but who have neither the means nor the inclination--not to mention the ability--to raise a pig and slaughter it for themselves. As a business, pork production is subject to the same economic forces that act in any kind of business. Consequently, the chances of a turnabout in the trend to fewer, larger, more intensive pork-production operations are akin to those of a return of mom-and-pop grocery stores in residential areas of every town in the land. Neither reversal is likely to happen in our lifetime.

INTENSIVE PORK PRODUCTION OPERATIONS

Reasons Behind the Trend

The trend to intensive systems of swine production accelerated markedly in the decade that has just ended. Several factors were responsible for this movement of pigs from dirt lots and pastures to confinement facilities. Land considerations comprised one of the more important causes. Rearing hogs on dirt requires tremendous acreages, and in many cases this represents unsound stewardship of a precious resource. Also, in many cases, this is simply economically infeasible at today's land costs.

Another critical factor was labor--both its availability and its cost. With the demise of the family farm goes the force of cheap labor upon which this kind of farming is based. Also, animal caretaking is a seven-days-a-week proposition, thus in order to attain a living standard similar to that of society as a whole, outside help was needed. Today's pork producer increasingly is having to hire people from the nation's general labor pool to do the chores formerly assigned to family members. Of course, the producer/employer must pay prevailing wages. Sometimes he must provide even additional incentives, because the work is hard and demanding. Thus, producers have had to expand and specialize their operations to the extent necessary to justify financially the increased outlays for hired help.

A third factor is the problem of waste management. Swine produce tremendous amounts of feces and urine. One finishing hog equals three adult humans in sewage output. Of course, the magnitude of the waste-disposal task rises in parallel with the size of operation. Because of the keen interest in environmental protection nowadays, regulations have been put in place at both state and national levels which in effect preclude the production of swine on many of the hills these animals populated in days past. For practical purposes, waste containment is achieved only with a confinement-production facility.

Benefits

While the foregoing have been the principal socio-economic forces behind the quickening adoption of intensive swine-management systems, the trend has not been without positive benefits to man and animal alike. Seasonal production cycles have been dampened considerably because it is more practical to farrow piglets the year around in a central farrowing house than in the shelters typically

used in extensive production enterprises. The changes this has wrought in hog marketing have increased the economic efficiency of pork production and processing. The ultimate beneficiary of all this in a capitalistic system is, of course, the consumer of the product.

Other pluses have to do with biological management. Providing steady supplies of a well-balanced diet and sanitary water is much easier in a confinement facility than outdoors. Predation of young pigs outdoors by wild carnivores is on the rise throughout the Corn Best, with the tacit approval of the government. But neither fox nor coyote is permitted inside a closed farrowing house or nursery. The perforated floors commonly employed in swine houses separate the animals from their own excreta, thus preventing them from practicing some of their more unsanitary habits: coprophagy and wallowing in their own excrement. Because enteric infections are major causes of disease and death in young pigs, the perforated floor alone is an important hygienic tool in disease management. Further, caretakers can obser e individual animals more thoroughly when they are close at hand and held singly or in small groups. Injuries and disease can be detected more readily, and remedial measures implemented more easily, as a result.

Importantly, a recent survey of large-volume pork producers revealed that, despite technological advances, they still by far consider sound husbandry the keystone of successful and profitable pork production. This point can not be overemphasized: excellent animal husbandry is the sine qua non of successful animal production.

The advent of larger units also has made it possible to upgrade the quality of management personnel. On many farms, pork production is no longer a sideline activity or one of several major competing enterprises. More and more, pork producers are multi-talented professionals who devote all of their time to the swine operation. Strong demand for well-educated and -trained management personnel has led to the emergence of specialized courses in intensive pork production at several agricultural colleges and vocational institutes.

Finally, with increasing size of operation come the economies of purchasing and marketing in large lots. While this usually enhances the profitability of an individual operation, the consumers of pork again are the ultimate beneficiaries in our kind of economic system.

THE QUESTION OF CRUELTY

The animal-production profession is like any other in that there are good producers and poor ones. When critics of modern pork production cite examples of cruelty to animals they refer to operations run by poor managers. The uninformed lay public--personally inexperienced in farming as most of them are--often are then encouraged to equate the cruel producer with the producer in general. In the process, the uninformed become the misinformed. Common sense tells us that an entire profession should not be condemned for the excesses of a few of its members. At the same time, animal producers as a group should admit that among their ranks are a few guilty of cruelty and then they must be willing--indeed, eager--to oust this element from the profession. (Incidentally, it also would be good if the various medical professions were as eager for this sort of self-policing in relation to cruelty to their patients as some would have animal-production professionals be in relation to cruelty to their chattel.) in the end, poor managers will not stay in the business long, and this is one built-in

control: a poor environment leads to poor animal health and performance, and consequently financial losses.

Abuse, Neglect, and Deprivation

Roger Ewbank suggests any producer-originated animal suffering falls into one of three categories: abuse, neglect, or deprivation. Abuse refers to obvious cruelty, such as beating an animal with a rod. Neglect occurs when an animal is confined and then denied a vital requirement, such as food or water. Deprivation is the form of cruelty most difficult to assess, as it involves the denial of certain, perhaps less vital, aspects of the animal's environment, many of which requirements have not even been definitely established.

Abuse and neglect are clearly cruel, and pieces of state and federal legislation outlawing both were passed many years ago. It should go without saying that progressive animal producers do not in any way condone, encourage, or support such cruelty toward animals. Therefore, the abuse and neglect categories of cruelty will not be considered further here. Whether or not animals are suffering from deprivation of certain specific behavioral or physiological needs is the issue at hand, and further discussion here will be limited to questions of cruelty via deprivation.

Anthropomorphism

Before addressing the issue of deprivation specifically, something should be said about the tone in which these issues have been raised. Often, when people state their objection to some aspect of animal management, they put themselves in the place of the animals. This attitude is called anthropomorphism. It is scientifically invalid. The requirements of animals are not the same as the requirements of humans. Indeed, the needs of various species of animals differ from one another, which should come as no surprise to anyone familiar with the diversity present in the animal kingdom. Duncan summed up the fallacies of the attitude of anthropomorphism neatly when he said:

> ". . . many of the criticisms and much of the argument, on both sides, has been unobjective or false in some other way. For example, one common argument put forward by the anti-factory-farming lobby is, 'How would you (a human being) like to be shut up in a battery cage all your life?'. This is what is called 'anthropomorphism' and attributes human feelings and mental experiences to animals, which is quite invalid. In fact, I would not like to be confined in a battery cage like a chicken, nor would I like to be fed regurgitated fish like a young sea bird, nor would I like to eat my own faeces like a rabbit! Man's personal likes and dislikes are of little relevance in the animal world."

Thus, when human feelings are transferred to animals, harm is generally done the animals. Specific examples of how actual animal needs differ from human needs and from human perceptions of animal needs will be given later.

GUIDELINES: FOUR ATTEMPTS

Guidelines for management of swine in such a way as to ensure the welfare of the animals have been put forth by several panels, some officially appointed,

others self-appointed. The famed Brambell Committee of Great Britian in 1965 suggested in summary five basic freedoms all animals should be provided (Table 1). Because these five freedoms were very broad, more specific guidelines have been issued in the meantime by the European Economic Community and the British Veterinary Association in 1979 (Table 2), by Teutsch and co-authors in 1979 (Table 3), and by Carpenter and co-authors in 1980 (Table 4). Some of the guidelines are frankly wrong, while others are supported by some scientific data. But many of the guidelines can not be based on any scientific evidence I am aware of.

It is of interest to learn, from Tables 1 through 4, that as time has progressed, some guidelines have been deleted, which might suggest they have been refuted, although no mention has been made of any such case. But the overall trend has been to add new, more specific--albeit in many cases unsupported--guidelines.

Table 1. Guidelines to ensure welfare of swine as issued by the Brambell Committee

An animal should be able to:
1. Turn around
2. Groom itself
3. Get up
4. Lie down
5. Stretch its limbs

Table 2. Guidelines to ensure welfare of swine as issued by the European Economic Community and the British Veterinary Association

Undesirable:
1. Intensive production systems which lead to cannibalism[a]
2. Castration of pigs intended for market before 160 days of age[b]
Further studies needed:
1. Close confinement of sows
2. Raising piglets in battery cages
3. Cannibalism

[a]Taildocking is acceptable if cannibalism is a problem.
[b]Interestingly the EEC also recommends castrating companion animals under general anesthesia, for sociological reasons.

Table 3. Guidelines to ensure welfare of swine as issued by Teutsch and coauthors

Pigs should be given:

1. Opportunity for locomotion at least one hour daily
2. Freedom for sow to build a nest
3. Provision of straw (50 to 100 grams per day per pig)
4. Large, solid lying area
5. Dunging area that is safe to walk on
6. Sufficient light for diurnal activity
7. Uninterrupted, fresh water

Also:

1. Management should be sufficient to make taildocking or keeping animals in darkness unnecessary.
2. Physiological and ethological needs should be met.
3. Domestic pigs have not adapted to denial of straw, life on fully perforated floors, nor deprivation of opportunity for locomotion.

Table 4. Guidelines to ensure welfare of swine as issued by Carpenter and coauthors

No husbandry system should deny environmental requirements of their basic behavioural needs. These include the following:

1. Freedom to perform natural physical movement
2. Association with other animals, where appropriate of their own kind
3. Facilities for comfort-activities, e.g., rest, sleep, and body care
4. Provision of food and water to maintain full health
5. Ability to perform daily routines of natural activities
6. Opportunity for the activities of exploration and play, especially for young animals
7. Satisfaction of minimal spatial and territorial requirements including a visual field and "personal" space

Deviations from these principles should be avoided as far as possible, but where such deviations are absolutely unavoidable efforts should be made to compensate the animal environmentally.

BRITISH CODES OF RECOMMENDATIONS

Around ten years ago, as a result of the Brambell Committee's report, the British government published codes of recommendations for the welfare to livestock, with a separate code for each species. In the preface preceding each code the basic requirements for the welfare of livestock were set down as: the provision of readily accessible fresh water and nutritionally adequate food as required; the provision of adequate ventilation and a suitable environmental temperature; adequate freedom of movement and ability to stretch limbs; sufficient light for satisfactory inspection; the rapid diagnosis and treatment of injury and disease; emergency provision in the event of a breakdown of essential

mechanical equipment; flooring which neither harms nor causes undue strain; and the avoidance of unnecessary mutilation.

In the case of Code No. 2--Pigs, 34 specific items were listed. The whole thing reminds one of the 4-H Club circular issued to nine-year-olds about to start pig projects. Following are some selected items verbatim:

1. The welfare of pigs can be safeguarded under a variety of management systems. The system, and the number and density of pigs kept at any one time, should depend on the suitability of the accommodation and the skills of the stockman. Badly-managed and unhealthy pigs will not do well, and it is essential that the stockman should watch for signs of distress or disease.

10. Excessive heat loss should be prevented either by the structural insulation of the external walls, roof and floor of the lying area or by the provision of adequate bedding. Sufficient bedding is essential.

16. Fresh clean water or other wholesome liquid should be available to the pigs daily.

23. Farrowing quarters should have a farrowing crate, farrowing rails or other device for the protection of the piglets.

27. Aggressiveness in dry sows presents a severe problem of husbandry. Where the sows or gilts are kept in groups, much depends on the temperament of individual animals; but the stockman should ensure that persistent bullying leading to severe injury does not take place.

34. Adequate shelter in winter and shade in summer should be available to all pigs.

Nothing earthshaking here, to be sure. And certainly nothing upon which to base the dawning of a new era of animal welfare; that will depend on a much fuller understanding of the subtleties of deprivation than this code even hints at. On the less subtle front, exactly what is a "suitable" accommodation? What is "sufficient ventilation"? What is "adequate shelter"? In this country, an extension swine specialist who could offer no more specific recommendations than these maxims represent would be hooted from behind his lectern and very well might lose his job. And the pork producer who in the first place knows no more specifically about a pig's requirements than was given in this code will not be in business next year. The Pork Industry Handbook, published by land-grant agricultural colleges throughout this land, is replete with the very specifics the British Code lacks.

Where the Rub Would Come

Of course, the point of all this is: The British efforts are the kinds of codes we should expect to emanate from our own Congress. They would have to be general enough to be acceptable to all parties concerned. The rub would come at the level of regulation promulgation and enforcement. Who would set the actual regulations? What would their qualifications be? Who would be enforcement officers? Would their basic training be in the area of animal production? How would the government train these people to make objective enforcement decisions in the field? Would all enforcement officers have the same notion of what

"suitable accommodation","sufficient ventilation", and"adequate shelter" mean? What about very subtle (possible) deprivations? How would potential officers be screened phychologically in regard to their tendency to anthropomorphize? And the list of serious questions goes on. The pork industry rightfully would demand hard answers to these hard questions.

SPECIFIC CONCERNS

Animal-welfare activists have expressed several serious concerns regarding certain techniques used widely in modern pork production. Once stripped of emotion and anthropomorphism, upon neither of which rational concerns and decisions should be based, many of their claims are unsubstantiated. Scientific evidence is sometimes meager, sometimes contrary to the welfarists' view, always derived from experiments which were difficult for even the brightest scientists to design, conduct, and interpret. The hypotheses often involve very subtle behaviors, which in the first place are generally difficult to measure. And then there is always the question as to how to quantify the cruelty quotient of depriving a pig of a specific aspect of its environment. After all, no environment--natural or artificial--contains all possible stimuli and opportunities at once. Hopefully, the following discussion of some of the specific concerns of animal-welfare activists will serve to outline our present knowledge of the respective situations.

Grooming

The Brambell Committee recommended that animals be given the opportunity to "groom" themselves. Wilson defines"grooming" as "The cleaning of the body surface by licking, nibbling, picking with the fingers or other kinds of manipulation. When the action is directed toward one's own body, it is called self-grooming; when directed at another individual, it is referred to as allo-grooming."

Whether or not swine allo-groom has never been demonstrated. Meese and Baldwin published evidence that pigs "examine"--probably by olfaction--each other's ears, head, flank, and anus during an agonistic encounter. The cleaning or social function of this behavior was not assessed, so we can not say that swine require the opportunity to groom socially, since the very existence of this behavior is in serious doubt. Certainly, self-grooming of the sort any pig engages in is possible in nearly any environment.

Any need for other types of social contact is also difficult to determine. Swine generally change their lying patterns in response to changes in effective environmental temperature. As temperature drops, pigs huddle together to conserve body heat; as it rises, they disperse. In a thermoneutral environment, pigs lie in loose groups. Their actual requirement for tactile contact per se--apart from the thermoregulatory function--has not been established.

Often adult swine are held individually. In the case of gestation stalls or tether arrangements, some tactile contact between adjacent animals is possible. Other forms of communication--including olfactory, vocal/auditory, and visual communication--are also possible.

The social needs of domestic swine are not well understood, and we can not transfer a human's or other animal's requirements to the pig. Each specie's social needs are probably unique.

Straw

Teutsch and colleagues suggested adding straw bedding to pig pens for comfort. With perforated floors and liquid waste-handling systems, straw is impractical since it can clog waste pipes. In general straw bedding can be used on solid floors. Proponents of straw bedding have suggested that it reduces boredom and provides a comfortable bed. They also believe that the lack of bedding--and therefore the presumed presence of boredom and discomfort--results in more social stress, nervousness, cannibalism, and skin and leg injuries.

The few facts regarding straw bedding do not support these claims. In an experiment by Kelley and co-workers, straw bedding did not influence pig agression even when the pigs were crowded. Straw-bedded pigs that were hungry fought a bit less than hungry pigs which had no straw; the hungry pigs apparently substituted some straw-chewing for some fighting. But in pigs that were not hungry, straw had no effect on agonistic activity. Madsen and associates also reported a large study in which straw bedding had no influence on cannibalism in swine.

It also has been suggested that prepartal sows require nesting material. Lack of bedding might be "frustrating", it has been said. Ethological evidence in a broad range of species suggests certain innate behaviors are programmed genetically; they are called "fixed action patterns". The sow's nest-building instinct seems to be an innate fixed action pattern. If so, the absence of nest-building material might or might not be "frustrating", but exhibition of nest-building behavior in the absence of bedding in no way provides conclusive evidence of a "frustrating" situation. Hansen and Curtis examined the activity of "crated" or "penned" prepartal sows with and without straw. Straw had no effect on standing or lying activities. Sows in crates did show more standing-up and lying-down behaviors, but of course they could not walk much in the crate, so sows in crates and pens might have expended similar amounts of energy. Clearly, further studies are needed before our understanding of these phenomena has progressed to the point where decisions about animal welfare would be valid.

The straw-bedding story is a good example of anthropomorphism. Humans feel they would rather stand bare-footed or sleep nude on straw than on concrete, so they assume pigs would prefer the same. From the foregoing, it should be plain that this is not necessarily true.

Floor Space

Gehlbach and coauthors reported floor-space requirements of growing-finishing pigs (Table 5). These floor-space recommendations were based on rate of body-weight gain. Ewbank and Bryant performed a similar study in Great Britian and Kelley and associates in the United States, and they found that when floor-space allowance was reduced below a critical level, aggressive behavior increased. Interestingly, that critical level was consistently below the floor-space allowance found by Gehlbach and co-workers to be optimal for growth rate. Thus, both pig performance and aggressive behavior are useful indicators of environmental quality.

It is of further interest that excessive space neither reduced aggression nor increased growth further.

Table 5. Minimum floor-space allowances (m^2/pig) recommended by Gehlbach and co-workers[a]

Pig weight (kg)	Slotted floors	Solid or partially slotted floors
11.5 - 18.0	.27	.36
18.0 - 45.5	.36	.54
45.5 - 68.0	.54	.81
68.0 - 95.5	.72	1.08

[a]Larger area was suggested during warm weather.

Table 6. Influence of floor space on pig weight gain and level of agonistic behavior

Space allowance (m^2/pig)	Weight gain per day (Kg)[a]	Weight gain per week (Kg)[b]	Number of agonistic encounters during Feeding[c]	Number of agonistic encounters during Standing[c]	Seconds of aggression[d]
.4 - .56 (crowded)	.68	4.5	101	57	32
.72 - .77 (normal)	.78	5.2	82	46	25
.90 - 1.1 (excessive)	.74	5.2	92	23	--

[a]Gehlbach *et al.*, 1966, based on the 70-90 kg body-weight period.
[b]Bryant and Ewbank, 1974.
[c]Ewbank and Bryant, 1972; 60 percent of agonistic encounters occurred during feeding.
[d]Kelly *et al.*, 1980.

Lighting

At least one panel has suggested that diurnal lighting be provided for pigs. Baldwin and Meese gave pigs operant switches via which they could select their preferred photoperiod. The pigs performed this task efficiently and called for light 72 percent of the time. Although the pigs preferred more light during the actual morning, their basic light-dark cycle was not diurnal, but rather an alternating photoperiod-scotoperiod cycle each hour of the day. Thus, since the pig does not prefer a diurnal lighting cycle, imposing such a shythm would place the animal in an environment it clearly did not prefer and therefore a potentially stressful situation.

Here again, it is shocking that committees with the purported intent of improving the life circumstances of animals would ignore information such as the pigs themselves have provided in this case. And here again, the basic problem probably is anthropomorphism; most humans experience one light-dark cycle daily, hence they assume this must be right for pigs, too.

Flooring

Development of perforated floors has been a major factor in making confinement swine production practical. Slotted floors eliminate the need for bedding, reduce labor requirements, improve sanitation as a tool in disease

management, and lead to more efficient waste-handling. Incorrectly designed and badly manufactured flooring materials can lead to a higher incidence and a greater severity of foot lesions and leg damage that can lead to secondary infections or posterior paralysis. The Scottish Farm Buildings Investigation Unit reports: "Badly designed and badly laid floors in confinement units caused foor injuries to 65% of pigs sent to slaughter."

Smith and Robinson found, in a study of the unusually high culling rates in pregnant sows confined to partially slotted stalls, that badly designed slats was the primary cause of partial or total posterior paralysis. The slats had been cast in such a way as to expose sharp edges when the molds were removed. Further damage occurred due to incorrect handling or installation and wear due to normal use.

Characteristics of floors that are associated with foot lesions and lameness include the nature of the slat edge, degree of traction, roughness, abrasiveness, slipperiness, and gap width.

Fritschen suggested that the higher incidence of foot injuries on slotted floors, as compared to soil, is due to a lack of resiliency in the floor material and that the pig's foot is not well-adapted to hard surfaces. This view has been supported by Smith and Mitchell, but Kovacs feels that the anatomy of the pig's foot is adequate to withstand the rigors of hard floor surfaces. Effects of hard floors are primarily leg-joint lesions, apparently resulting from irritation while the animals are lying.

According to Fritschen, the portion of the floor that is slotted seems to have more effect on rear-leg anomalies than on front-leg or front- or rear-foot problems. Fully slotted floors have more wearing effect on foot claws than do 25-percent-slotted floors. Fritschen also suggested that, on a partially slotted floor, accumulation of manure and wasted feed may provide a cushion for the volar surface of the foot claw.

Floors that are half plastic slats and half solid concrete resulted in a lower level of claw lesions, and Fritschen has concluded that pigs reared on 20-cm-wide slats, made of flat, smooth-surface concrete with a pencil-round edge, have fewer and less severe claw lesions.

Schmoldt and Heyden and Schleiter and colleagues stated that fewer lesions should occur on solid floors, regardless of surface. But, in contrast to this, others have found severe foot problems on solid, nonslotted floors, as well.

Smith and Mitchell observed a reduced incidence of knee damage in piglets reared on concrete floors treated with epoxy-resin or chlorinated-rubber paint. Gravas compared three types of flooring--concrete, epoxy-painted concrete, and a floor covered with a rubber mat--and found that type of flooring had little effect on the number of skin lesions, although wound diameter and depth were greatest on rubber mats and smallest on plain concrete.

Robertson and coauthors noted that sows on slotted or solid floors were comparable in behavior. However, those on slotted floors seemed to spend more time lying. Gravas reported that sows prefer floors covered with rubber mats.

Research is presently being conducted to find a more comfortable type of flooring for swine that is also less chilling and less slippery than materials in

current use. Meanwhile, most forms of lameness found in pigs can be prevented by sound management, and remedies are enhanced by careful observation for any pig that develops a foot or leg problem.

Stalls and crates

The gestation crate has been attacked as being extremely stressful to the sow. The grounds on which this notion is based are not scientifically sound. One approach to determining the validity of these claims is to study the performance of the sow and her litter of piglets. Results of such studies have been conflicting. Backstrom found that sows confined in crates during pregnancy delivered more stillborn and mummified piglets than did sows which had been free in a pen. On the other hand, England and associates observed no significant difference in the number of piglets born alive or dead when comparing sows which had gestated on pasture with those confined to stalls. Admittedly, Backstrom's results were based on larger numbers of animals, but still the Oregon research probably is more representative of North American production systems.

Fraser studied the effects of tethering and straw on the behavior of gestating sows. The results he reported are interesting, but his paper has become controversial because some readers have taken some of Fraser's speculations and upgraded them to the level of conclusions of scientific fact. There also are some experimental-design and inference-space problems in the work. A case in point is the significant difference observed in chewing and manipulating straw between sows with and without access to straw. It comes as no surprise that sows with no straw in their environment chewed and manipulated straw less than those with access to it.

Also, tethered sows with straw bedding tended to chew the straw, while tethered sows without access to straw spent more time bar-biting. These data alone can not be interpreted to mean that depriving the sows of bedding caused an anomalous behavior, bar-biting. The straw could have directed the sows' oral behavior to the bedding. In both cases, the sows devoted roughly equal time to oral behaviors.

Farrowing crates came into widespread use for several reasons, including the advantages they have in terms of floor space required and waste management, but especially the way they prevent sows from lying on their own piglets and killing them. On the other hand, there have been claims that this kind of confinement is unduly stressful to the peripartal sow.

Robertson and co-workers found a significantly higher number of piglets alive at three and eight weeks of age in the stall farrowing system than in the pen system. Devilat and associates confirmed this finding.

Some adverse effects have been associated with the farrowing crate, too. Peo suggested that it might result in slow parturition and lactation problems in sows genetically unadapted to confinement. Hansen and Curtis found that sows held in stalls sat-up or stood-up more often during the 48-hour period preceding parturition than did those in a pen. These results indicate that confining sows to a stall during the immediate prepartal period influenced their behavior, but it is still questionable as to whether any undue stress was present.

There remain a large number of questions about gestation and farrowing crates and stalls. But one thing is certain: There is no reason to abandon

crates and stalls based on our present scientific knowledge. Before any decision can be made in response to animal-welfare concerns, that additional information will have to be in hand.

Tail-Docking

Pigs are relatively aggressive by nature. They are feisty anywhere they are kept. But the problem has become more important in confinement production systems. Usually, the tails and the ears are the targets of aggression. An episode of tail-biting can start as an innocent, exploratory nip of the tail tip that draws blood, and then further biting is stimulated until only the stump remains. Docking the piglet's tail before a week of age is the most effective means of preventing subsequent tail-biting, but this practice has been indicted as an unnecessary mutilation.

Of course, tail-docking does not remove the reason tail-biting occurs in the first place. It has been speculated that overcrowding, absence of bedding, low dietary fiber concentration, boredom, and other factors may lead to tail-biting, but attempts to experimentally induce an episode by environmental alterations have been uniformly unsuccessful. Van Putten reported that bad atmospheric conditions in a swine house can lead to tail-biting, but results of research at the University of Illinois have not supported this contention.

Colyer speculated that tail-docking is unsuccessful in reducing total cannibalism, as the attention of the offending animals is simply redirected toward the ears or the legs. In contrast to this, Penny found only a small number of pigs had bitten ears and concluded that it is unlikely that ear-chewing and tail-biting are closely related. Far from increasing the incidence of ear-chewing, tail-docking seemed to reduce it.

Penny also observed, in a huge sample of pigs examined at an abattoir, that tail-biting was present in 904 of 7795 undocked pigs, whereas only three of 4016 docked pigs had bitten tails. The efficacy of tail-docking in reducing the incidence of this natural vice seems clear.

Castration

The present practice in this country of castrating almost all male piglets intended for slaughter is due to consumer preference, not producer preference. Boars generally grow faster than barrows and have slightly greater feed-conversion efficiency and leaner carcasses. Furthermore, castration is a time-consuming operation, increases the chances of infection and a growth set-back, and boars are feistier than barrows, especially at heavier pre-market body weights.

The compound, 5α-androst-16-ene-3-one, has been isolated from boar fat, but not from barrows or gilts, by Patterson. This compound is responsible for a pungent, obnoxious odor given off during the cooking of fresh or cured pork. The odor is detectable by many consumers in meat from boars slaughtered at 200 pounds live body weight and above; hogs are commonly slaughtered at a body weight of 220 to 250 pounds in the United States. Of course, slaughtering hogs at 240 pounds instead of 160 pounds, as is common in the British Isles, means around a third fewer hogs must be killed.

Griffiths and Patterson studied consumer acceptability of boar meat by presenting men and women a watch glass in which 800 ng of androsterone had been

placed. In general, they found that both sexes disliked the odor, and women found it more unpleasant than did men. Due to the adverse effect on the acceptability of the meat, various attempts apart from neonatal castration have been made to eliminate or suppress the odor. Till now, none has been successful.

CONCLUSION

Animal-welfare organizations have been expressing their concerns and making their insinuations and asking their questions and levelling their charges about intensive systems of swine production. There is another side to this issue.

The biological-management techniques in pork production never will be perfect. As we understand it today, each animal has a range in each of many environmental components over which it is not suffering undue stress or duress. At the same time, the respective ideal ranges are much narrower. It is the broader ranges which must be sought. We can always strive of the ideal, but we must admit it is unlikely to be achieved. That simply is not the nature of environmental management in animal agriculture. In reality, decisions must be made and balances must be struck.

The confinement approach to animal production has brought many positive benefits relating to cruelty to animals. This is especially so regarding the animals' major requirements, which are associated with potential abuse and neglect. Shelter from the climatic elements has been provided, so the pigs no longer need suffer from extremes of the thermal environment. Steady supplies of nutritious feed and sanitary water are available, and special care is taken to ensure that each animal gets its required share of both. Young pigs are protected against predators. Sanitary environments are much more easily achieved and maintained. Daily inspection of each animal is possible, and attention to disease and injury is prompt.

Furthermore, confinement production systems fit in with America's societal concerns and legendary agricultural efficiency. The waste is contained so it does not end up polluting a stream. Confinement operations attract a high level of management and caretaking personnel. And often land can be used more effectively for crop production than for pasture, so that today each American farmer feeds 49 of his fellow Americans and 15 people in other countries.

On the other hand, scientific evidence, which for the most part has yet to be generated, might some day prove that certain negative factors relating to deprivation of subtle needs are present. It might be that some elements of which confinement environments are devoid are essential requirements for swine. I challenge the animal-welfare movement to switch from accentuating the negative to supporting the positive, to divert a major portion of their funds from underwriting public-information and legislative-lobbying activities to supporting bona fide scientific investigations of these matters which concern them so greatly. I challenge the animal-welfare organizations to prioritize their concerns and then to set up grant programs to provide qualified researchers the money it takes to conduct well-controlled studies in this area.

Rational changes in swine-production systems will not be possible until the kind of information that would come out of such research is available. The pork-production industry will welcome enthusiastically any such changes that involve both documented improvements in the lives of their animals and additional benefits in terms of the quantity of food produced and the efficiency of that production.

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University of Illinois

PORK INDUSTRY CONFERENCE

December 3-4, 1981
College of Agriculture
Department of Animal Science
Cooperative Extension Service
Agricultural Experiment Station
University of Illinois at Urbana-Champaign

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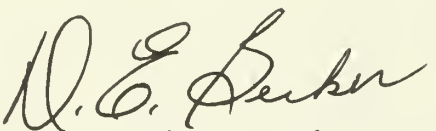
WELCOME TO THE PORK INDUSTRY CONFERENCE! It is a pleasure to have you attend.

Commercial swine production has become industrialized. It is now a business in which experts in animal production, more than ever, must be concerned about finance, personnel management, labor efficiency, quality control, industry image, government regulation, etc. In other words, it is big business which requires constant awareness of advancements in technology, changes in organizational management and government policies and changes in the factors of production. Only those who make an effort to be informed in all facets of the business will be likely to operate profitably.

This conference is designed to assist swine producers to stay abreast of developments vital to their business. We hope that it will be recognized as and become a part of a continuing education program for professional, large-scale swine producers.

You are here because you need and value information to apply to your business. We hope to provide it.

We will be interested in your suggestions to make future conferences of maximum benefit to you.



D. E. Becker, Head
Department of Animal Science

The Department of Animal Science at the University of Illinois

THE DEPARTMENT OF ANIMAL SCIENCE IS CONCERNED WITH THE MULTIDISCIPLINARY ACTIVITIES associated with the production, care, and utilization of animals useful to mankind. It includes primary fields of study in behavior, genetics, environmental physiology and management, meat science and muscle biology, nutrition, and reproductive physiology. Beef cattle, horses, poultry, sheep, swine, and various companion and laboratory animals are studied to assist animal producers and owners to obtain more efficient performance, more economical production and other such improvements which ultimately benefit the general public.

Our staff includes about 140 people of whom 50 are academic staff members; 40 are nonacademic staff members in the offices, research farms, and laboratories; and about 50 are part-time teaching or research assistants who are pursuing graduate study. Several of the senior academic staff members have received national and international recognition for their accomplishments.

The work of the Department is divided into extension, research, and teaching. Extension or off-campus teaching is handled by eight full-time staff members. Each extension specialist conducts seminars, clinics, field days, etc., for livestock or poultry producers. Their primary work is to apply new research findings to the business of animal production or product processing.

Over the years the Department has had very active and productive research programs. Some of the more notable research accomplishments include the discovery of the value of antibiotics in livestock feeding, the elucidation of the amino acid needs of swine and poultry, the utilization of inorganic nitrogen by ruminants, the development of simplified corn-soybean meal rations for swine feeding, and the development of confinement production technics, particularly the use of slatted floors. Current research studies pertain to such topics as recycling of animal wastes, decreasing prenatal mortality in gestating sows, the inheritance of blood groups in swine, exercise physiology in horses, alcohol treatment of soybean meal, factors affecting amino acid needs of domestic animals, and animal behavior.

With the recent increase in student numbers, the teaching load in Animal Science increased significantly. At present our Department provides instruction for about 2,800 students a year in the classroom, and staff members advise 480 undergraduate (mostly juniors and seniors) and 90 graduate majors. Our graduates have many opportunities for employment.

The future of the Department of Animal Science appears bright. Meat consumption and the use of animals for companionship and in recreational activities are at all-time highs and seem likely to increase further. Such an expanding animal industry will require an educational program to produce well-trained animal scientists and research programs geared to produce new and improved technology.

University of Illinois
PORK INDUSTRY CONFERENCE
December 3-4, 1981
Ramada Inn, Champaign

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Current and Future Problems in Pig Production

R. BRAUDE

May I, first of all, thank the organisers of this event for their invitation to me to participate. Exactly thirty years ago, I spent nine months at your university and still have very pleasant memories of that time. I have learned a lot from H.H. Mitchel, W.C. Rose, T.S. Hamilton, C.B. Johnson and T.S. Terrill, and watched with admiration the careers of the then youngsters: Gene Becker, Sam Mistri and Dick Forbes, and others.

On an occasion like this, I have decided to discuss with you some of the topical and often controversial problems within the pig production industry, wherever located. After more than forty years of involvement, the best that I can do is to give you my assessment and I hope, make you think, and possibly discuss with me, your own attitude to these problems. Often there is no single solution to a specific problem. What may be right on one farm need not be right on a neighbouring farm. And personally, I never stop wondering about how much one has to know, to know, how little one knows.

Of course, I had to be selective in my choice of topics, and because of the limitation on time, I will often use telegraphic style to cover as wide a range of problems as possible. I will start with one of the most important problems - that of economics. Here not only knowledge of facts is essential, but also the right attitude to the problems encountered.

I am sure, that we can all agree that pig keeping is a business, and its main, if not the only, purpose, is to make a profit. Nobody keeps pigs as a hobby, and a profit is what is left after covering expenditure involved. It is most important to recognise that 70-75% of expenditure is in the cost of feed, about 10% in the cost of animal raw material (piglets) and the remaining 15-20% must cover all the rest. (Table 1). The only income is from the sale of pigs. All too often these simple facts are forgotten, resulting either in a loss of profits or forcing the price of pig meat and products above the level at which they can remain really competitive with other meats available to the consumer. One should always keep in mind, that the main asset of pigs, and one that we should do everything possible to retain, is that pigs can provide meat which the consumer wants - cheaply. Watching cost effectiveness of every operation must be the key to the production of cheap pork and pork products. We are very lucky that pork is a very versatile and competitive commodity compared with other red meats, but it is essential that it should retain an attractiveness also when compared with poultry.

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I often wonder how many people have asked themselves the simple question: Are you working for yourself or for the money lenders? Cost of capital is obviously a crucial factor, but it worries me when I see demands for increased productivity, just to cover the excessive working and fixed capital overheads. We want higher and higher productivity to increase profit and, if possible, to lower the price of pig products to the consumer. Pig keeping has a great asset - it allows a person, by hard work and intelligence, to build up, relatively quickly, a small unit to a reasonably large enterprise. However, it must be done slowly. There is no point in starting with debts which eventually will strangle one before the target can be reached.

There are only three factors that really matter in modern pig production, and one accepts that in all of them management, labour and stockmanship play an important part:

1) Productivity of the sow.
2) Efficiency of feed conversion.
3) Quality of carcass, meat and meat products.

All three are, of course, dependant on genetic make up. On this occasion I will limit my remarks on breeding to a few generalisations: a) tremendous progress has been made. b) Future progress must be based on improving the best. Raising of the average will result as a consequence, and should not be the target. c) Improvement of pure 'breeds' is rightly regaining momentum. d) Crossbreeding is an important tool, but assessment of quality of each parent is as essential in crossbreeding as it is in pure breeding. e) Methods of testing of breeding stock are changing. In the U.K. we are now moving from testing at stations to testing on farms. (Table 2).

The main factors affecting the productivity of the sow are:

1. Number of pigs born alive per litter
   (stillbirths should not be overlooked).
2. Number of pigs marketed
   (includes losses through mortality, but losses through morbidity should not be overlooked).
3. Number of litters per year
   (time of weaning).
4. Longevity of the sow
   (number of litters during lifetime).

Table 3 relates the first three factors. However, I would like to draw particular attention to the importance of the fourth. Too often has this factor been ignored in the past. Examples in Tables 4 and 5 make it clear that productivity of the sow becomes rather an empty term if this factor is overlooked.

A reasonable target for the future: 12 pigs born alive, 10% losses, weaning at 4-5 weeks of age, and 6-8 litters per sow. However, I do believe that the sow fecundity factor offers good prospects for exploitation. I have in mind the 'China rumours' and Table 6.

Before I pass on to my comments on efficiency of feed utilisation, I wish to deviate slightly to a related subject, and introduce to you the just published ARC Nutrient Requirements of Pigs. You are all familiar with the NRC publications in this field. The ARC's, and it is a second edition, completely revising the 1967

edition, is a much more comprehensive document, reviewing in detail and discussing all the aspects involved. Obviously, I cannot discuss details of the 350 page document, but I have chosen a few items for comment:

I would like to quote to you our definition of requirement: Requirement is defined as the amount of nutrient that must be supplied in the diet to meet the needs of the normal healthy animal given an otherwise adequate diet in an environment compatible with good health. The assessment of requirements for specific nutrients aims at providing the best possible guidance to persons who have to formulate diets or are involved in the day-to-day problems of feeding pigs.

Things have changed during the last few decades - and they are still changing. Productivity of pigs has increased markedly, and one recognises more and more that efficient feeding is not static, but rather a dynamic process, involving many factors which have to be integrated. Rather like a big symphony orchestra, where every instrument plays a vital role.

Nowadays when we think about requirement we should not restrict ourselves to asking how much of a nutrient is required, but also enquire what it is required for.

This led us to approach the subject of requirements by two routes: an empirical and a factorial one, and a most interesting exercise it was, and I recommend a study of it.

Next, a few details which may be of interest to you: As far as energy requirements are concerned, we recognise that many factors affect them: genetotype, sex and environment, but we put a special emphasis on 'expected performance' - all pigs are not equal. We decided to go for meat and avoid fat, and to continue expressing requirements in terms of Digestive Energy, and using jules as units rather than calories. As here in USA you are using the TDN system and others are using different systems, it is important to realise that an adequate conversion table now exists. (Table 7).

We started to query the validity of faecal digestibility values, but have nothing to replace them with. The ileal digestibility values provided an interesting exercise, but, to-date, have not resolved the problem.

As far as protein is concerned, we all now recognise that the term crude protein is not a very specific one (CP = N x 6.25). We all are loosely talking about amino acids. Protein is made up of essential and non-essential amino acids, usually at least twenty recognised ones, and it has become clear that the composition of protein is so variable that some means of creating meaningful order must be attempted. We accepted the new concept, suggested by researchers at Nottingham University, of ideal protein which is defined as protein in which the balance of amino acids is exactly matched to the animals' requirement for the particular function, or combination of functions, and which cannot be improved by substitution of any quantity of one amino acid for another. Table 8 give the adopted composition for ideal protein. Only one comment on protein for application in practical feeding: As the pig grows older, its requirement for protein decreases. As dietary protein supplements are expensive, it is a mistaken practice not to reduce, at intervals, the protein content of diets used. A reasonable compromise is to have three diets: 1) starter, 2) grower and late gestation - lactation, 3) finisher and early gestation.

As far as minerals are concerned, controversy exists and it is difficult to find sufficient information on which to base specific recommendations. The subject is further complicated by the lack of knowledge of interaction between various minerals, and between minerals and other nutrients. We have gone for slightly higher Ca and P amounts than in the earlier edition.

Considerable gaps of knowledge are obvious when dealing with vitamins, and for some, the dietary requirements have not been established. My practical advice, both on minerals and vitamins, is that I would support the old fashioned view that diets of the type used in the UK (and I believe this would apply also to the maize-soyabean diets used in the USA) need to be supplemented only with Ca, P, salt, zinc, retinol and calciferol (note that I am using the active vitamin forms to describe vitamin A and D). I certainly do not support the view that everything but the kitchen sink should be added, or that ingredients should be added profilactily to protect against a small risk of deficiency. For example, only in some circumstances could an addition of cyanocobalamin (vitamin B_{12}) oo of biotin be justified, and at the present stage of knowledge, both are too expensive to be recommended as supplements to normal diets.

Only a few words on performance promoting additives. I will refrain from commenting on antibiotics. You know all about them. I will concentrate on copper, which you have ignored, or perhaps overlooked. The copper story arose from an observation indicating that young pigs have a craving for copper, they show preference for copper when confronted with a choice of several metals, and they have the ability to discriminate in favour of diets containing copper. These early observations are often forgotten, when decades later, some people speculate about the safety and welfare aspects involved in copper supplementation.

In the United Kingdom during the last 25 years at least 200 million pigs received diets supplemented with 200-250 mg Cu/kg diet, and, as far as I know, not a single person or animal has, in any way, suffered from it. It is much more difficult, virtually impossible, except as a speculation, to estimate the usage throughout the world, but I venture a suggestion that at least 2 billion pigs received diets supplemented with copper and benefited from it. The summarised evidence is presented in Table 9. From the accumulated evidence, it appears that the response to copper supplementation is:

1) greatest, when about 250 mg Cu/kg diet is added.
2) greater with young pigs, and declines with age of the pig up to approx. 5-7 months old, when most of the pigs are slaughtered,
3) smaller, the higher is the basic performance of the pigs involved. This seems reasonable, as whatever the mode of action of copper may be, it cannot improve the performance beyond a 'physiological ceiling'. Whatever the definition of "a ceiling", and whenever it is reached (and it will be quite a long time, if ever) there will be no case for improving further the quality of the diet which allowed to achieve it.
4) 10-15% of the pigs on experiments did not respond to copper supplementation. The lack of response could not be attributed to any specific cause.

I hasten to add that on the four points mentioned in the preceding paragraph, the evidence is by no means conclusive, and I personally, would refrain from generalisations on these matters.

And now a few remarks on the efficiency of feed utilisation. During the last 50 years, great progress has been made. The feed:gain ratio was reduced from 4.5 to 2.25 with normal diets containing 12.5 Megajoules of digestible energy per kg. (Fig. 1). Obviously, progress on such a scale cannot continue - somewhere there must be a ceiling. There must be a physiological limit to the biological processes involved. It may be unrealistic to expect further improvement of more than say 10%, leading to a F:G ratio of less than 2.0, or if one is inclined to wishful thinking, a F:G of 1.8 may be put as the ultimate target. One must realise, however, that the better the performance of the pig, the smaller becomes the possible improvement due to whatever measures one initiates. Another aspect needs stressing: the smaller the responses - the more difficult it is to measure them. For example, in Fig. 1 figures are shown to illustrate that a 5% response is of such magnitude that we can measure it in a reasonable experiment, but when it comes to 2.5% improvement (the shaded area), it becomes rather unlikely that statistically meaningful results can be obtained from, a, however, well-designed experiment. Certainly the experiments of the future will have to be more sophisticated, and a larger number of animals will have to be used. It may also become debatable whether the small improvements at the end of the road are of practical value in economic terms. Eventually a point may be reached where further improvement may not be possible, and then the target will become how to maintain the maximum performance already attained.

It is not only the quantity and the qaulity of the diets that are important, but also the methods of feeding. Here I have selected six important topics for comments:

1. Wet v. dry feeding. We believe that liquid feeding will dominate the scene in large units. (Table 10).
2. Restricted v. ad lib. feeding. These terms are meaningless unless related to a specific diet composition, e.g. properly balanced diet with 12.3 MJ DE/kg (2800 Cal/kg). Pigs up to a certain liveweight can be fed this diet ad lib., but if intended for the bacon market (about 90 kg liveweight) - controlled feeding must be introduced during the last period in order to ensure best utilisation of feed and best carcass quality.
3. At what weight should the pigs be slaughtered? With the type of pigs available in this country it is rational to cater for one of the three market weights, 'pork' (up to 60 kg), 'cutter' (up to 80 kg) or 'bacon' (up to 90 kg liveweight). The weight of the latter category may eventually be increased, possibly up to 105 kg, when the genetic make-up is improved. I believe that overwhelming evidence exists against the 'heavy pig' (118 kg and above) except in very special circumstances.
4. Frequency of feeding. There is no advantage in frequent feeding. When controlled feeding is introduced, once daily is quite adequate.
5. Trough v. floor feeding, and meal v. pellets. Floor feeding will give satisfactory results, if pelleted feeds are used: meal on the floor is wasteful. When fed in the troughs there is no advantage from pelleting, provided waste is avoided by using properly designed troughs intended for meal feeding.
6. Simple v. complicated formulations. Provided the essential nutrients are included, the simple mixtures have obvious advantages.

My comments on carcass and meat quality will be limited to three aspects

only. It is now obvious to everyone, I hope, that current and future requirements of the market are for lean pigs. An excess fat is no longer wanted, and all possible steps must be taken to eliminate it. The problem of slaughter weight deserves more attention from producers and processors. The fact that different markets require carcasses of different weight offers a scope for intelligent exploitation. I believe that the stage has been reached when one can no longer justify the castration of pigs in commercial herds. It may take some time before this view is generally recognised, but the writing on the wall is quite clear. Traditionally, male pigs have been castrated, and in the past there were very good reasons for doing so. However, there can be no doubt that boar pigs grow faster, utilise their feed more efficiently and produce leaner carcasses. It may come as a surprise to you that currently, about 25-30% in the UK, 40-45% in Ireland and about 80% in Australia, of boars destined for meat are not castrated, and that in the UK the House of Commons Agriculture Committee recently recommended "that agreement be thought within the European Community to prohibit castration of pigs except on veterinary grounds".

There are two other general topics that I wish to comment on briefly: health and welfare:

Health - or lack of it - may become the barrier to progress. The idea that one has to put up with some of the diseases is no longer tenable. The targets for the future are clearly delineated by the activities in the UK of the Pig Health Control Association (PHCA). It has pioneered the concept of closed herds, and it runs schemes controlling freedom from four main diseases: Enzootic pneumonia, dysentery, Aujeszky's and atrophic rhinitis (pilot scheme). The symbol of the Association has not attained worldwide recognition, and buyers of stock anywhere should get acquainted with the principles on which activities of this Association are based.

At this point of time, one would be remiss if one would not mention, however briefly, welfare. I see no conflict whatever between efficient animal production and adequate caring for the animals kept for producing meat and other products for their masters. We must accept the need for reasonable standards, but I regret that we lack adequate knowledge to define them. People argue about acceptable density of animals in pens. I have no doubt that in many cases what is reasonable has been disregarded. I have been interested in some recent Dutch studies which indicate that fewer numbers of pigs per pen, fewer than generally accepted, may be enhancing performance and is cost effective. However, we must be adamant in rejection of unwarranted accusations and unsound speculations. There is, for example, nothing wrong in keeping the pigs in the dark. Often, in discussion, it quickly becomes clear that people arguing against it are not aware of the fact that pigs can see in the dark. We also must insist that the argument that certain things are 'not natural' is so ambiguous as to make it virtually meaningless. Is milking of a cow a 'natural procedure'? does it become less 'natural' if one milks with a machine? Is weaning at 3 weeks 'unnatural'? and what basis is there to consider 8 week lactation as 'normal'?

The last research project initiated by me is proving to be an interesting story, which may prove to be of major practical significance. We encountered, by chance, a heavy infestation by mites. The mite involved is Acarus siro (wrongly called flour mite). In favourable conditions (hot and humid) it will multiply very rapidly. Table 11 gives values obtained under controlled conditions. We investigated potential losses of nutritive value of meal infested with the mite, and in Table 12 some of the results are summarised. The losses can be very

substantial. A survey is now in progress to ascertain the incidence of infestation under practical pig keeping conditions.

Finally, I would like you to know that the pig creates many problems to the research workers who use it as a model for advancing knowledge concerning man. The pig has many features which are similar to man. Its digestive system, for example, is very similar indeed.

Table 1. Economics of pig production

Expenditure	%		Income	
			Sale of pigs	
Raw material (piglets)	10			
Feed	70-75			
All the 'rest'				
Housing & equipment				
Labour & management				
Veterinary services				
Loans & interest				
Taxes				
Misc.	15-20			
	100	= £.....		
	Profit	= £.....		
		£.....	=	£.....

Table 2.

Central Testing (MLC)

	1970	1973	1976	1980
Boars tested	5,220	4,040	3,320	2,640
Boars returned, No.	1,930	1,880	1,550	1,180
%	36.9	46.5	46.6	44.7

On farm Testing (MLC)

	1971	1973	1976	1980
Boars	5,000	8,000	10,400	14,000
Gilts	47,000	69,400	70,100	54,000

Table 3.

No. of pigs reared/sow/year

No. pigs /litter	Losses % 0	10	20	No. litters /sow/year
9	18.0	16.2	14.4	2.0
	20.7	18.6	16.6	2.3
	23.4	21.1	18.7	2.6
10	20.0	18.0	16.0	2.0
	23.0	20.7	18.4	2.3
	26.0	23.4	20.8	2.6
11	22.0	19.8	17.6	2.0
	25.3	22.8	20.2	2.3
	28.6	25.7	22.9	2.6
12	24.0	21.6	19.2	2.0
	27.6	24.8	22.1	2.3
	31.2	28.1	25.0	2.6

Table 4. Number of pigs per sow 'per year' in lifetime

10 pigs born/litter
20% losses = 8 pigs/litter

	No. of litters					
	2	2½	3	3½	6	8
Total no. of pigs in lifetime	16	20	24	28	48	64
No. of pigs/year in lifetime						
8 wk weaning = 2 litters/year	10.7	11.4	12.0	12.4	13.7	14.2
3 wk weaning = 2½ litters/year	11.4	12.3	13.1	13.6	15.4	15.7

Table 5. Number of pigs per sow 'per year' in lifetime

12 pigs born/litter
10% losses

	No. of litters					
	2	2½	3	3½	6	8
Total no. of pigs in lifetime	21.8	27.0	32.4	37.8	64.8	86.4
No. of pigs/year in lifetime						
8 wk weaning = 2 litters/year	14.4	15.4	16.2	16.8	18.5	19.2
3 wk weaning = 2½ litters/year	15.3	16.6	17.7	18.3	20.8	21.2

Table 6.

Number of pigs reared related to number born and percentage lost during rearing

Number born	% lost during rearing					
	40	30	25	20	15	10
10	6.0	7.0	7.5	8.0	8.5	9.0
12	7.2	8.4	9.0	9.6	10.2	10.8
14	8.4	9.8	10.5	11.2	11.9	12.6
16	9.6	11.2	12.0	12.8	13.6	14.4

Table 7.

Factors for the interconversion of some common energy units used in nutrition (Kielanowski (184))

Feed unit	SE kg	TDN kg	SFU or FE	OU	DE MJ	ME MJ	NEF, MJ
1 kg SE	1.00	1.01	1.43	1.67	18.49	17.78	12.84
1 kg TDN	0.99	1.00	1.41	1.65	18.24	17.57	12.68
1 SFU or FE	0.70	0.71	1.00	1.17	12.93	12.47	9.00
1 OU	0.60	0.61	0.68	1.00	11.09	10.67	7.70

Table 8.

Composition of the 'ideal protein'

	g/kg protein
Lysine	70
Methionine + cystine	35
Threonine	42
Tryptophan	10
Isoleucine	38
Leucine	70
Histidine	23
Phenylalanine + tyrosine	67
Valine	49
Non essential N x 6.25	590
	994

Table 9. Improvement in the performance of growing pigs due to supplementation with copper sulphate, 250 mg Cu/kg diet

Period	Data	No. of tests	Total no. of pigs/ treatment	Percentage improvement, weighted mean, range in brackets Daily gain	Feed/Gain
1955-65	World literature (Braude 1967)	83	1215	8.1 (-12.0 to + 25.2)	5.4 (-5.2 to + 12.6)
1965-75	World literature (Braude 1975)	119	2630	9.1 (-15.6 to 37.1)	7.4 (-13.2 to 24.1)
1955-80	(NIRD tests)	33	312	6.0 (+2.2 to + 14.5)	4.8 (0 to + 10.8)

Table 10.

Advantages associated with controlled liquid over dry feeding
1. Better performance - small, but significant
2. Restricted water intake prevents wastage of water
3. Reduced water excretion - amount of slurry can be drastically reduced
4. Mechanization made simpler and cheaper - transport of liquid more efficient than of dry material
5. Automation of controlled feeding more accurate
6. Water installation to individual pens unnecessary
7. Pre-mixing of main dietary ingredients unnecessary
8. Bulky ingredients easily incorporated into diets

Table 11.

Flour Mite (Acarus siro L.) infestation

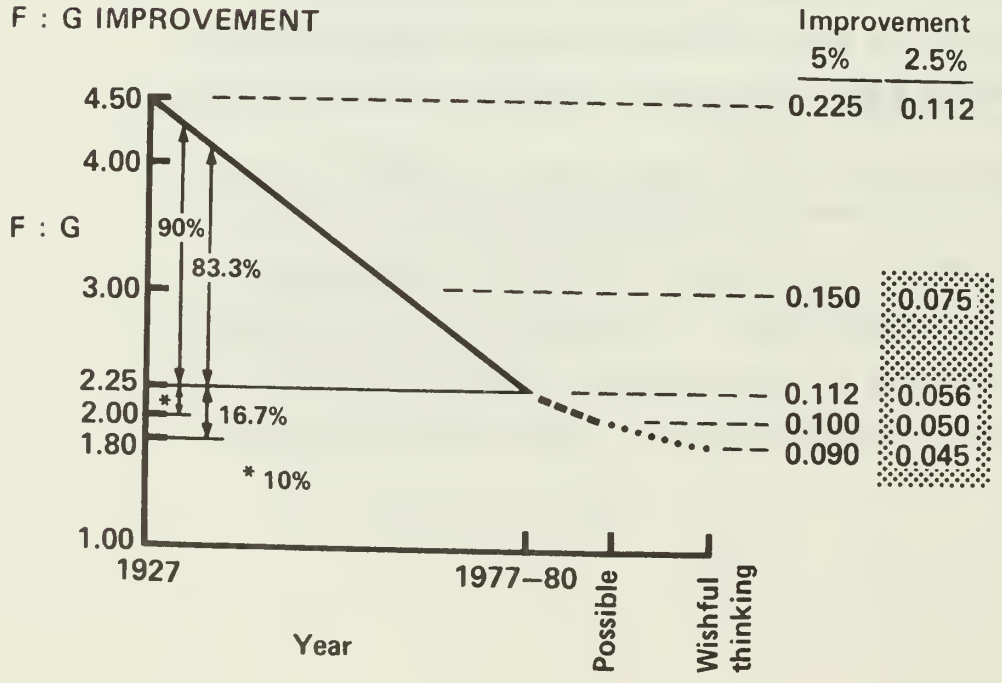
Feed	Storage time	Mite numbers/g
Infested	3	470
Infested	6	1600
Infested	9	6600
Control	9	1.4

Table 12.

Effect of flour mite infestation on nutritive value of feed

Mite numbers/g	Dry matter mg/g	Gross energy MJ/g	Mean of 16 amino acids g/16 g N	Proportion of N in amino acid form
Control	883 -	14.7 -	5.46 -	81.1
470	839 (-3.0)	14.9 (+1.4)	5.09 (-6.8)	75.7
1600	757 (-14.3)	13.2 (-10.2)	4.50 (-17.5)	66.8
6600	738 (-16.4)	13.5 (-8.2)	3.39 (-37.9)	51.7

Fig. 1.



How We Use Basics to Develop Tomorrow's Seedstock

LYNN A. COLE

Many commercial producers are asking, "What is happening in the seedstock industry?" In the 60's they told us to make them meatier--a groove down the spine and big, bulgy hams. We discovered that mothers made like this had problems farrowing. PSS and PSE were associated with this type. Then in the 70's they told us to make them longer, taller, looser, flatter, bigger headed and tailed. It didn't take long for us to discover that soundness was a problem with these long-legged rascals and that big heads and tails didn't really make them grow faster. In fact, many of the so-called long, loose ones were actually aged runts and sired more of the same. Our packers are also complaining about the loss of muscling. Now there is a trend toward shorter, thicker, fatter ones. We know it costs more to produce fat than lean and, furthermore, our housewives don't want fat. Just what kind of hog should we be producing? Who should we listen to? Who is going to help us find the ideal hog?

Yes, the commercial producer, like most of you, has been asking these questions and others as you have followed the advice of breeders, packers, and specialists through the last quarter century or more of changes. It's true, we have improved the carcass and then lost some progress. It's true, we improved mothering ability and then lost some of it. It's true we improved growth rate somewhat. It's true we improved feed efficiency greatly. Soundness has always been a concern--progress is a hot topic for debate. Where are we headed? Have we learned any lessons? How should selection be made and what should be the criteria? Let's take a look at how the future could unfold.

We must return to basic reasons for producing pork. What are these reasons? They are very simply: 1. Make money. 2. Feed people safely and efficiently a desirable product. You all knew that, didn't you? Of course! Up till now, I haven't told you anything new. Maybe I won't. Maybe all I'll do is put pork production into perspective--a different approach. Then possibly, I might tell you something new. Back to perspective. Who needs to make money?

1. Pork producers
2. Truckers--all phases
3. Packers
4. Processors
5. Retailers

What factors influence this? Environment, management, health and heredity--all are involved but we will be considering only heredity involvement.

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1. Producer
    a. High conception rates
    b. High percent of bred sows farrowing
    c. Large litters farrowed
    d. Large, heavy litters weaned
    e. Rapid growth from weaning through market
    f. Efficient conversion of feed to milk and meat
    g. A population of animals that are free of defects causing economic loss and soundness problems that result in premature culling of breeding animals or sacrifices on market animals.

2. Truckers
    a. Freedom from PSS
    b. Soundness

3. Packers, processors and retailers
    a. Freedom from PSS and PSE
    b. Soundness
    c. Ruptures, cryptorchids, etc., that cause loss
    d. A carcass that yields a high percentage of high-quality cuts that are in demand

As we analyze the profit-producing traits it is obvious that we can make a very concise statement as to the type of hog that will make: A female that, while on a minimum of nutrition, will conceive, retain, farrow and nurse large uniform litters of heavy pigs of the type that will grow rapidly and efficiently to slaughter weight with freedom of soundness and defect problems and ultimately produce a carcass which the consumer will relish to dine upon. The sire may or may not need to possess all of these traits, depending upon the use of the offspring--for slaughter only or as replacement females.

A very broad and yet concise statement that pretty well sums it all up. But extremely difficult to ever achieve! In fact, impossible with present practices. An even more concise statement, but just as evasive to achieve, could be set forth in this goal: To produce the largest amount of the most desirable product in the least time on the least cost from the fewest animals.

My opinion is that formulas must eventually be accepted by the seedstock industry which will emcompass all these areas before we discover what the hog that wins in the showring really should look like. In the meantime, frankly, it would be nice if all judges and breeders would suddenly discover that they were too busy keeping records and evaluating them to come to the showring. The formulas should be put together for the various breeds in various ways, depending upon their use in crossbreeding programs. All breeds should not be alike except for color and ear shape.

We, at Cole Swine Farms, believe we are approaching the problem with specific goals in mind which will largely solve these problems and produce the profitable hog of the future which is desired by the consumer. What evidence do we have?

In gathering the war data, most of our tools and techniques are readily available to most breeders if they will only take the time and effort to use them. These include the small hog scale for determining average daily gain, feed efficiency, days/230#, 21-day litter weights, etc. Another tool used daily is our electronic scale for weighing feed into feeders. Every boar and gilt is sono-

rayed to determine backfat, percent lean cuts and square inches of loin eye. We use a pregnosticator on each sow to be sure she is pregnant. Then we go two steps further than most producers by putting the data we collect into computers, then analyzing the print-outs instead of the raw data.

Some might say, "Why go to so much effort to produce a pig?", or, "We can sell all the breeding stock we can produce without doing all that testing. Why should we spend all that unnecessary money and time?" My answer to these people is, "Sure, it is work and it is very costly. But, if you are really serious about improving seedstock, as I am, you must use every kind of modern technology that can be developed to soundly test, evaluate, and select the most profitable animals for propagation. Nothing less will suffice, or someone will replace both your product and you!"

As you have probably surmised by now, we are interested in improving every facet of the seedstock population. We stress different traits in each breed, but strive to keep balance in our efforts. In my estimation, such costly defects as hernias, hermaphrodites, ridglings, cryptochids, diverted or tied penises, infantile reproductive tracts, lack of libido in boars, inability to settle in sows, and blind or inverted teats must be eliminated regardless of how good the animals are otherwise. Therefore, we discard all dams who transmit these inherent problems as well as their progeny. Sires who transmit these traits at levels above the average for other sires in the herd are also disposed of regardless of value or records achieved. This is our first criteria for selection.

Our second selection criteria is to identify structural soundness problems that are judged to be economically distressing. Seedstock propagating these problems are also released from service.

After these two criteria have been fulfilled, we then have two more criteria of selection. These two vary in importance between and within breeds according to what we wish to accomplish. One is individual feedlot performance data on the individual, as well as that of the parents and sibs, including ADG, days to 230, FE, BF, LEA and percent LC. The other is the sow productivity index ranking of the dam, sire, sire of dam, and sow family.

Finally, there is one more selection phase--visual appraisal for type. This is one radical difference between our selection procedure and most--as most producers have this as their first priority in selection. However, in spite of the fact that I and my employees are good "evaluators" (if you will) of the parts of the pig--that is, which is the longest, flattest muscled, loosest, or whatever, we don't really know what we should be looking for. And, furthermore, as evidenced by recent trends, I'm not sure anyone else does. Therefore, if, after finding animals that will meet all of our specifications up to visual appraisal, we still find we have more than we need, we will get brave and say, "OK, I don't like the type of that one--she is not a keeper." Perhaps we are wrong, hopefully we are right. Only time will tell.

This brings me to the real meat and potatoes of my presentation. You have seen that we are putting a great deal of emphasis on the sow productivity index. Let's take a closer look at the data collection, formulation, analysis, and application of such a sophisticated technical evaluation tool of SPI.

First of all, let's consider data collection. Facts that need to be submitted to the computer are:

1. Litter ID
2. Sow ID
3. The sow family
4. Sire of the sow
5. Breed of the dam
6. Breed of the sire of the litter
7. Parity (how many litters the sow has had)
8. Number of pigs born--total and alive
9. Number after transfer (litters should be standardized)
10. Number and weight of pigs at 16-26 days (we weigh each Tuesday)
11. Farrowing date

Data other than this, such as speed of farrowing, ease of farrowing, birthweight, sow pen habits, sow dispostion, etc., are not necessary as this type of data only indicate the causes for the SPI being what it is. We do record this type of information as further detail, but it is not necessary.

Given this raw data, our computer at OSU is capable of adjusting for several factors so as to make all data comparable. Such as:

1. Breed of dam--we all know (even if some breeds don't want to admit it) that there are vast differences between breeds. We'll take a very close look at this a little later.

2. Parity--we also know that gilts generally have smaller and lighter litters than sows. The computer has been programmed for this and compensates accordingly so that gilts can be computed on an equal basis. It is also programmed to give slightly more value to the SPI as more litters of history are accumulated. The more litters a sow has contributing to the index, the more valuable it is considered to be.

3. Contemporary grouping--all sows that are put through at one time are considered a contemporary group, and each individual is compared only to the others within that group. This removes such variables as seasonal weather influences, TGE, scouring, "corn-fielditis", etc.

After these adjustments to the raw data are supplied, the computer then segregates the following information:

1. It ranks, in order of Breeding Value, or SPI, all the sows submitted in the last contemporary group by breed. Beside the SPI it also lists the farrowing interval since the last litter. It reprints the raw data on this page also.

2. The summary section gives the average of litter size, farrowing interval, and litters/sow/year on this group.

3. The overall sow rankings section ranks within each breed every sow upon which a record has even been computed.

4. The sow family summary then within each breed ranks the sow families of which it is composed.

5. The Sire of Sow summary does the same for each sire of sow.

Computer programs are wonderful when properly formulated. These formulas must be based on latest research available. As we get deeper into our investigations and applications of such programs, we have discovered to our sheer amazement that sow productivity has been perhaps 24-35% heritable--not 5-10% as we

used to think--not 15-20% as we believed when the selection formula was being developed by Ohio researchers. Could the key be only discovery and proper application of all the factors influencing conception, gestation, farrowing and lactation? We now believe this to be true. It's exciting to think about the possibilities.

Another factor not compensated for by the computer, but reported beside the SPI (as I mentioned earlier) is farrowing interval. I am extremely happy to see it reported, as I feel that it is really one very crucial factor in the determination of profitability of the swine enterprise. We do not disregard it as we study our monthly print-outs. I feel there is a possibility for improvement of OSU's formula by including an adjustment factor (plus or minus) for length of farrowing interval. As I have stated before in various articles, the ultimate measure of a sow's productivity should include, along with the number born, number at 21 days and weight at 21 days, the days required to produce that weight. I feel that an excellent commercial herd should produce 1# of 21-day-old pigs/day/sow (including gilts starting at 7½ months or breeding age). This would be accomplished by having large litters from good-milking sows that settle when they are supposed to. If any one of these three factors is lacking, production falls. Therefore, I again emphasize the often overlooked, and even more often ignored, factor of farrowing interval.

I am sure that the only thing that will prevent the industry from making rapid strides in sow productivity will be the reluctance of swine breeders to pursue space-age technology in their operations. The computer program outlined here is the newest and most reliable tool available and should be used with sono-ray, scales, pregnosticators, etc., to develop the productive hogs of the future, just as space scientists are using computers with other technologists to build better space ships. Let's make the hog of the future productive in the farrowing house, fast and efficient in the feedlot, and a savory treat for the consumer.

Relationship of Stress to Pork Quality

DAVID G. TOPEL

INTRODUCTION

In the 1950's, swine producers in the United States started to select for reduced fat deposition and increased muscle deposition in a swine population that had as much fat as muscle in the carcasses of market weight pigs. The rate of improvement was slow until the early to middle 1960's. At this time, the industry developed excellent grade and yield programs which paid producers a premium for trim and muscular carcasses. Also, an abundance of carcass shows were developed and the carcasses were evaluated and ranked on the basis of closely trimmed ham and loin percentage. The consumer was demanding lean pork and the swine producers in the United States were challenged to use intensive selection pressure for reduced fat deposition and increased muscle deposition, especially in the ham and loin.

Observations and published reports of pork quality traits by meat scientists in the late 1950's and early 1960's pointed out that the incidence of pale, watery pork was increasing. Research with the Danish Landrace by Ludvigsen (1957) and Wismer-Pederson (1959) indicated a relationship between the pig's ability to adapt to preslaughter stress and their postmortem muscle characteristics. Briskey (1964) prepared an excellent review article on factors which cause the development of pale watery muscle in pork carcasses. This review pointed out that preslaughter stress was a major factor in the development of pale, watery pork.

The swine industry in the early 1960's placed limited importance to the increased incidence of pale, watery pork muscle, but the packing industry realized that pale, watery pork had a greater skrinkage during processing (Topel, et al. 1972) and the color stability in cured products was a problem when pale, watery pork was used (Wismer-Pederson, 1960; Moerman and Krol, 1969). At this time the incidence of pale, watery pork in the U.S. swine population was 18-20 percent (Forrest et al., 1963) and the loss to the meat packing industry was several million dollars a year.

In 1967, a second dimension to the pale, watery pork problem was observed at Iowa State University. Very muscular pigs were transported approximately five miles from the swine farm to the classroom on the ISU campus in February. They were transported from a cold to a warm environment and two of the eight pigs expressed unusual "shock-like" signs a few minutes after they were unloaded from the truck. This was the first observation of the signs currently known as the Porcine

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Stress Syndrome (PSS). Pigs which develop the syndrome often die and they also have a high incidence of pale, watery muscle. The Porcine Stress Syndrome is the advanced stage of the same genetic abnormality which causes the development of pale, watery muscle. In the late 1960's and early to mid-1970's the incidence of the PSS greatly increased and death losses from this condition became a major concern to swine producers and the packing industry.

The Livestock Conservation Institute reported that approximately 35 percent of U.S. hog producers in the United States had encountered the condition and have experienced death losses from the Porcine Stress Syndrome. This resulted in the loss of several million dollars each year for the U.S. swine producers.

Swine producers also associated leg and feet soundness problems with extreme muscling traits and even lowered disease resistance was often associated with heavy muscling in pigs. Because of these associations, a high percentage of the U.S. pork producers selected against well muscled pigs the last six to seven years to reduce the stress problems, reduce the soundness problems and improve disease resistance traits in swine. This was an unnecessary approach to reduce the incidence of the Porcine Stress Syndrome and related adaptative problems. This paper will describe research results which could be used to reduce or eliminate the PSS and not decrease muscle percentage.

MUSCULARITY AND MEAT QUALITY

Several research reports show a small ($r = .3$ to $.4$) but positive association between the degree of carcass muscling and the development of pale, watery pork muscle (Ludvigsen, 1960; Briskey et al., 1966; Topel et al., 1967; Hedrick et al., 1968; Jonsson, 1968; Judge et al., 1968; Steinhauf, 1968; Dalrymple and Kelly, 1969; Dildey et al., 1970; Weiss et al., 1971). Other research has shown no relationship between swine muscularity and the quality traits of pork muscle (Berry et al., 1970; Charpentier et al., 1971; Skelley and Handlin, 1971; Staun, 1970). The variation in these research results may be related to differences in breeds or lines within breeds which were used for the comparisons. Some very muscular lines have normal meat quality and other very muscular lines have very poor muscle quality.

When the current literature is summarized, it can be concluded that stress adaptation traits are positively associated with pale, watery muscle and heavy muscling characteristics of pigs. It must be pointed out, however, that the relationship is low and it is therefore possible to select for improved muscularity traits and also desirable muscle quality traits. The stress adaptation characteristics associated with the PSS can also be eliminated by careful selection criteria with no decrease in muscle deposition.

PORCINE STRESS SYNDROME SIGNS

One of the most convenient and cheapest methods to reduce the incidence of the PSS is to detect the signs by visual appraisal and eliminate these pigs as replacement animals. Therefore, a review of the PSS signs may be of value before we discuss other methods which are available to select against the PSS. Stress susceptibility problems in pigs must be described as a syndrome rather than a single abnormal characteristic. When stress-susceptible pigs are subjected to extreme excitement such as fighting during marketing or when they show

resistance to normal management practices, a series of signs often develop. These have been reported as the porcine stress syndrome (Topel et al., 1968).

Early signs of stress adaptation difficulty in the pig are muscle and tail tremors. Further stress can result in marked irregular breathing, alternating blanched and reddened areas of the skin, rapid increase in body temperature, cyanosis and development of an extreme acidosis condition. The next stage in the syndrome results in a total collapse, marked muscle rigidity and hyperthermia; death often occurs after the muscle rigidity develops in a shock-like state.

Based on survey information, less than one percent of the U.S. swine population expresses the PSS condition. Therefore, we should be able to remove all bloodlines which carry the stress genes and still have a wide base for genetic selection of muscular, sound and vigorous pigs. The inheritance traits of the PSS are well enough established to apply these principles to practical breeding and selection programs. A review of the inheritance research will be presented before its application is discussed.

PSS AND PSE INHERITANCE

A recessive type inheritance of the porcine stress syndrome was first reported by Christian at Iowa State University in 1972. This hypothesis was later supported by results of Ollivier et al. (1975), Minkema et al. (1976), Webb and Smith (1976), Christian (1977), Smith and Bampton (1977) and Jensen (1981). Results of test matings at the Iowa Experiment Station (Table 1) are consistant with those expected with autosomal recessive inheritance. The Iowa State study used both purebred and crossbred litters and showed that the inheritance is the same for both purebred and crossbred swine. The recessive inheritance at a single locus was reported by Ollivier et al., 1975 and Minkema et al., 1976. The locus has been designated Hal (Andresen and Jensen, 1977) and comprises the alleles N and n (Minkema et al., 1976). Thus, the Hal locus comprises the genotype Hal^N Hal^N (NN), Hal^N Hal^n (Nn) both non-susceptible to stress and Hal^n Hal^n (nn) susceptible to stress and exhibit the PSS signs and develop PSE muscle.

Jensen (1981) reported on a project where the nn-line (PSS positive) and the NN line (PSS negative) sows were mated to NN- and nn-boars. Results are shown in Table 2. Significant differences between the two homozygous types were found for average daily gain from 55 to 200 pounds and the slowest growing pigs were the stress-susceptible type. Eikelenboom and Minkema (1974) and Verstegen et al. (1976) also reported that PSS pigs gained slower than normal pigs. Carlson et al. (1980) reported that PSS pigs were more efficient in feed conversion than the normal pigs (PSS pigs had a feed to gain ratio of 2.77 and normal pigs had a ratio of 2.90).

The carcass muscle percentage for the normal Danish Landrace pigs in Jensen's (1981) study was 60.0 and the PSS pigs had 64.3 percent muscle. The percentage of carcass muscle in the Iowa State PSS pigs reported by Carlson et al. (1980) was 54.1 for the PSS pigs and 51.5 for the normal pigs. Note the major difference in muscle percentage between the normal pigs and the PSS pigs in Denmark vs the United States. The 60 percent muscle in the normal Danish Landrace is an indication of the potential we have for improving muscle percentage in the U.S. pig population and still eliminate the PSS genes from the breeding herds.

PSS DETECTION METHODS

Elimination of or reduction in the incidence of this hereditary problem depends on identification of the PSS animals and particularly the identification of the carriers of the defective gene. This identification is essential for the subsequent elimination from the breeding herd. Although absolute methods of identifying the genetic carriers are not currently available, several techniques are successful in identifying pigs which express the PSS signs.

Visual Appraisal

Classification of pigs based on their appearance by experienced evaluators provides an inexpensive and rapid means of detecting the PSS animal. Visual indicators include extreme muscling with basketball shaped hams, small stature and tight skin in the belly and jowl region. When physically stressed, the affected animals show the PSS signs reported early in the paper (Topel et al., 1968). Although the visual method can range from 40 to 80 percent accurate with experienced evaluators, the methods lacks the objectivity desired for widespread use by the industry and often leads to misdiagnosis of heavy-muscled, stress resistant pigs. Selection criteria used in the show rings over the last 5 to 6 years have made attempts to reduce the PSS problem by visual appraisal. This has resulted in a major decrease in the incidence of PSS in the U.S. pig population. With the use of more objective methods, we can continue to select for muscle deposition and greatly reduce the PSS genes from the swine population. More objective methods will be discussed in the next three paragraphs.

Creatine Phosphokinase (CPK)

Whole blood or serum levels of CPK are associated with the PSS (Hallberg et al., 1979). Often improper collection techniques have been used for CPK analysis and this pitfall can result in a poor relationship between the CPK levels and PSS signs in pigs. Also, differing physiological conditions of the animal prior to collecting the sample for CPK analysis can cause wide variation in normal as well as PSS pigs. Hemolysis, organ specific diseases, disorders not directly related to stress adaptation, and contamination of blood CPK enzymes by needle puncture through muscle tissue are other sources of increased CPK levels which can reduce the predictive value of blood CPK levels in stress-susceptible pigs. When blood samples are carefully drawn from an ear vein 2-8 hours after a physical exercise has been uniformly imposed on all pigs to be tested, CPK measurements have produced accuracies varying from 60-85 percent for the homozygous pigs (NN). This method cannot identify the heterzygous genetype (Nn) and therefore it has several limitations. The CPK method has to be used in connection with a progeny testing program to identify the carrier or heterzygous genetype. It has the advantage of being a simple and easy method for producers to use on purebred or commercial farms. A few drops of blood on a special type of paper is sufficient to determine the blood CPK levels. The cost for each sample is approximately 2 to 4 dollars.

Halothane Screening

Exposure to halothane (a gas type anesthetic) offers an accurate means of detecting stress-susceptible pigs. The procedure was developed by Christian (1974) and Eikelenboom and Minkema (1974) and it involves exposure of 7 to 11 week old pigs to 6 percent halothane for 3 minutes or until evidence of muscle rigidity is apparent. The PSS pigs will develop extreme muscle rigidity within

3 minutes and the normal pigs will not develop muscle rigidity when exposed to the anesthetic halothane. Halothane is administered via a closed system through a large animal mask with oxygen as the carrier. This procedure seldom is lethal to PSS reactors when administration is stopped immediately upon observation of the first signs of progressive muscle rigidity. The procedure is approximately 98 percent repeatable (Alva-Valdes, 1979). False negative responses to halothane are generally preceded by periods of malnutrition or prolonged stress. This test should not be used if pigs are known to be exposed to prolonged stress or are in a condition of malnutrition. This method, like the CPK method, cannot identify the heterzygous genetype (Nn) better known as the carrier of the recessive gene. In order to eliminate the recessive stress gene(s) from genetic lines, the halothane method must be used in a progeny testing program to identify which pigs carry the gene(s) and remove these individuals from the breeding herd. This process is currently being used by some commercial companies who sell hybrid boars.

The cost of the halothane is approximately 5 to 6 cents per pig, but the machine used to administer the halothane is a major cost item. Used machines can often be purchased from hospitals for $200.00 to $300.00. New machines would be more than $3,000.00. Large producers could justify this cost, but it may not be an economically feasible method for smaller producers. The CPK method would be the best alternative.

Blood Typing

Dr. Ben Rasmusen (University of Illinois) was the first person to relate blood types in pigs to stress-susceptibility or PSS traits. Erythrocyte typing of the H and A-O systems offers potential for detecting not only the PSS animal but the carrier (Nn) of the stress gene as well (Rasmusen and Christian, 1967). Animals of the H^{-}/H^{-} blood type and those A-O negative with the a/a H type and crosses among these two types (H^{a}/H^{-}) are nearly always halothane positive in one Yorkshire population. Although similar relationships are sometimes observed in other swine populations, exceptions are common, suggesting the association is caused by linkage with some crossing over. Imlah and Thomson (1979) report blood typing to be approximately 80 percent accurate in classifying pigs for degree of stress-susceptibility. This method has the greatest potential to eliminate the stress gene(s) from the swine population as it is the only method currently available which can identify the carrier (Nn) of the recessive gene in the swine population. Further elucidation of blood typing technique could result in a highly accurate field testing procedure for the elimination of the stress gene(s) and still allow the swine industry to select for improved muscle deposition. Further research is needed before the blood typing method is used by swine producers.

SUMMARY

The porcine stress syndrome and the pale, watery condition of pork muscle associated with the syndrome are genetic abnormalities and therefore genetic selection offers the only sensible approach to reducing the incidence of the PSS in the swine population. If sires are identified as normal for the stress gene(s) and are homozygous (NN) these sires can be used on pigs which are stress-susceptible (nn-genetype) or heterzygous (Nn) for the stress gene(s). The homozygous boar would cover up expression of the stress syndrome and greatly reduce the incidence of PSE muscle. Some breeds have a low incidence of the PSS gene(s) and the Duroc breed is one example. The use of a Duroc boar in a crossbreeding

program will greatly reduce or could eliminate the development of the PSS or PSE muscle in certain lines. The Pietrain breed has an extremely high percentage of pigs which are stress-susceptible and this is also a very muscular breed with very large ham development. A cross of the Pietrain breed with a Duroc would greatly reduce the stress problems in the first cross.

Herds encountering a high frequency of the disorder should consider halothane screening of all potential within-herd replacements. Elimination of all positive reactors and their parents, sibs, and half-sibs is advised. CPK measurements of all purchased seed stock and a check for blood lines known to have the problem will reduce the risk of reintroducing the problem. Because the relationship between muscle deposition and the PSS are positively related, producers must always use both criteria in a selection program. The positive relationship is not high and that allows the industry to carefully select for improved muscling and still eliminate the PSS gene(s).

Pigs which have the PSS gene(s) often grow slower (Jensen, 1981) and are more efficient (Carlson et al., 1980). Therefore, these factors must be taken into consideration if a selection index is used. If feed efficiency is used in the index as well as muscling, it is very important to use an objective method for determining the degree of stress susceptibility in the pigs used for the breeding herd. Feed efficiency and muscling are two traits which will be used in selection programs in the future if the swine industry is to be competitive with other meat sources such as poultry.

Even though we don't have a 100 percent accurate method to eliminate the stress gene(s) from the swine population, acceptable methods are available which can be used at the producer level. If these are combined with a progeny testing program, the swine industry can greatly reduce the PSS and PSE problem and continue to increase muscle percentage in the U.S. pig population. We have a need for much improvement when the U.S. pigs are compared with pigs from the European countries, particularly Denmark.

The U.S. is not as competitive in the world export market as we should be due to the excess fat and lower muscle content of the carcasses available for export. The demands of the domestic consumer as well as the world market for lean pork places an important responsibility on the swine producers to select for reduced fat and increased muscle deposition. We can produce an efficient, sound, vigorous and muscular pig free of stress problems if we use these factors in a good selection program. It will take dedication on the part of the producer, but the long term returns will offset the added costs.

Commercial suppliers of hybrid boars have already incorporated these concepts into their selection program and I hope other producers who have not considered these alternatives will give them serious consideration.

Table 1. Stress classification of offspring from various mating types

Mating type	Litters	Stress classification	
		Positive	Negative
Stress x stress	33	194	4
Stress x carrier	73	230	309
Carrier x carrier	40	67	224
Stress x control	15	0	85

Note: Stress classification is based on response to halothane anesthesia at 8-12 weeks of age. Data from Christian, Iowa State University.

Table 2. Means and standard deviations for production and carcass quality traits in the Danish Landrace

	Genotype					
	NN		Nn		nn	
	Mean	Std dev.	Mean	Std dev.	Mean	Std dev.
Number of pigs	32		74		61	
Daily gain (55 to 200 lbs)	1.60	.18	1.44	.16	1.37	.18
Carcass length, in.	38.4	.2	38.6	.2	38.1	.18
Percent muscle	60.0	1.9	62.1	1.5	64.3	1.9
Percent PSE	21.9		23.0		73.8	

Note: The genetic classification was based on the response to halothane administration. Data from Jensen, 1981.

Table 3. Least-square means of production and carcass traits of PSS and normal pigs

Item	Type of pig	
	PSS	Normal
Halothane exposure, sec.	82	180
Percent muscle	54.1	51.5
Carcass length, in.	28.8	29.3
Feed efficiency	2.77	2.90
Muscle color[a]	29.60	21.60

[a]Color expressed as percent reflectance. Values of 18 to 24 would represent normal color. Values of 28 to 34 would be PSE. Data obtained from Carlson et al., 1980.

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Amino Acid Nutrition–A Factor in Production Efficiency

D.H. BAKER AND R.A. EASTER

FACTORS AFFECTING AMINO ACID UTILIZATION

Animal Efficiency

There are many factors which affect the efficiency with which amino acids are utilized for protein synthesis and growth. First and foremost, it must be understood that intake of a given amino acid in relation to its requirement level has a profound effect on the efficiency with which that amino acid is used by the body. Efficiency is greatest in the linear area of growth (i.e., between a point just above maintenance to one just below the requirement level). Obviously, with submaintenance intakes or with intake levels above the requirement for maximal growth, amino acids are not used efficiently for growth. In fact, at superadequate levels, amino acids are merely catabolized, the carbon skeleton of which is used for energy and the nitrogenous portion excreted in the urine as urea.

Lean tissue synthesis is efficient relative to fat tissue accretion. Thus, in general, the efficiency of amino acid utilization for growth is greatest in very young animals whose weight gain is primarily made up of protein. Efficiency thus decreases as an animal advances in age and weight. Because lean is more efficiently deposited in the animal carcass than fat, lean strains or breeds of animals (or those administered anabolic agents) utilize amino acids more efficiently than fat strains of animals. However, despite this increased efficiency, some work shows that lean pigs, for example, or those fed anabolic agents, may require somewhat higher levels of dietary essential amino acids than fat-type pigs. For this same reason, boar pigs (intact males) and gilts (intact females) require higher levels of dietary amino acids than barrow pigs (castrated males), principally because the latter are less efficient in lean tissue synthesis but more efficient in fat tissue deposition.

Another general factor which can affect the efficiency with which individual amino acids are utilized is their relative turnover rates in the body. Lysine, for example, is turned over (released from body protein and then either reutilized or excreted as urea and CO_2) more slowly than isoleucine. Hence, maintenance studies have shown that the net utilization of absorbed lysine is more efficient than the net utilization of isoleucine. Turnover rate may also be influenced by whether or not there exists in the body an endogenous store of a given amino acid. To illustrate, muscle tissue contains free carnosine, a dipeptide, which could be thought of as an endogenous source of histidine. Likewise, cysteine is contained in the RBC- and liver-tripeptide, glutathione. When glutathione is turned over in the body, cysteine (available for growth) is released.

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Amino Acid Bioavailability

Proteinaceous ingredients are generally counted to furnish the bulk of the animal's amino acid requirements. Because there may be a plethora of factors affecting the efficiency with which these amino acids can be delivered unaltered to the absorptive sites in the gastrointestinal tract, the utilizable portion (i.e, the bioavailable portion) of the total level of amino acid present is generally less (80 to 90% of the total) than 100%. Some amino acids are more vulnerable to loss of bioavailable activity than others.

Most experts feel that it is, at present, premature to formulate feeds on the basis of bioavailable amino acid concentration. There simply isn't good enough methodology and, thus, there are not reliable values for the vast array of feed ingredients used in livestock feeding. Until such time as good quantitative data are available on the bioavailable amino acid content of each feed ingredient for each species of interest, one would be well advised to simply assume an average bioavailability value (eg., 90%) and use this in formulation. One should remember, however, that requirement estimates put forward by most countries who do this kind of thing (eg., National Research Council of the U.S.) assume a degree of unavailability of amino acids in feed ingredients for the animals whose requirements are being estimated.

Lysine Bioavailability

Lysine is particularly sensitive to heat damage via the Maillard or "browning" reaction. Also, heat, and particularly heat together with alkaline treatment, may result in crosslinking of protein chains, with lysinoalanine being formed at the crosslinks. Lysine bound either in Maillard linkage (with carbohydrate-type residues having free carbonyl groups) or as lysinoalanine has totally lost its biological availability. Thus, overheated soybean meals or cottonseed meals with high levels of free gossypol (gossypol contains free aldehyde groups that can bind in Maillard linkage with the epsilon amino group of lysine) contain lower levels of "available" lysine than properly heated soybean meals or degossypolyzed cottonseed meals. Of course, proper heat treatment of many oilseed meals is critical to elimination or detoxification of trypsin inhibitor factors, hemagglutinin factors, goitrogenic factors, and other inhibitor factors present.

Sulfur Amino Acid Bioavailability

Methionine and cystine are both vulnerable to oxidative, acid, and alkaline processing losses. While sulfur amino acid (SAA) bioavailability in feed grains such as corn is high, the availability in feedstuffs such as feather meal and poultry by-product meal is considerably reduced. During processing of these ingredients, lanthionine, a crosslinked amino acid product of cysteine and dehydroalanine, is formed. The cysteine so bound in this fashion loses 60 to 70% of its SAA bioactivity. Thus, given the "total" SAA makeup of feather meal (i.e., methionine, cystine and lanthionine), the bioavailable portion of the total is probably no greater than 60%. Of course, crystalline SAA (generally methionine), by virtue of the exposed free alpha amino group, is subject to the Maillard reaction. This would be of particular concern in young animal diets where a reducing sugar (reactive with free amino groups) such as dextrose or lactose might be present in the diet. The same could be said, however, for any free crystalline amino acid present in a diet containing reducing sugars.

Many SAA table values in feedstuff composition tables are in error due to the difficulty of obtaining good analytical estimates of methionine and cystine composition. The normal procedures used for intact protein analysis involving HCl hydrolysis cause some destruction of both methionine and cystine such that analytically determined values frequently represent underestimates of the SAA content actually present. The performic acid oxidation procedure (preceding acid hydrolysis) represents an improvement. In this procedure, methionine is assayed chromatographically as methionine sulfone and cystine (cysteine, also, if present) is measured as cysteic acid. The performic acid oxidation procedure almost always gives SAA values higher than those obtained by the conventional acid hydrolysis method. Thus, older table values generally have SAA values which are underestimates of the real levels of SAA present. This has sometimes caused feed formulators to supplement diets with methionine or methionine hydroxy analogue when, in fact, the diet was not in actuality deficient in SAA to begin with.

Recent evidence from the University of Illinois and the University of Georgia has demonstrated that growth-promoting levels of copper (100 to 250 ppm) fed to poultry and swine may interfere with SAA utilization. The copper is thought to bind with free SH groups in the body (eg., cysteine, reduced glutathionine), causing cysteine, for example, to be oxidized to cystine (or to be excreted in the bile as the SH-copper complex). Cystine *per se*, of course, cannot be utilized for protein synthesis. It must first be reduced back to cysteine. Copper, however, interferes with this reaction. As a result, diets marginal in SAA are probably stressed somewhat by presence of 250 ppm copper in the diet.

Tryptophan and Threonine Bioavailability

These two amino acids have frequently been reported to be lower in bioavailability than most other amino acids. The reason for this is unknown, although tryptophan, like methionine and cystine, is well known to be subject to losses from either acid or alkaline treatment of proteins. Tryptophan tables values for corn and other grains represent overestimates of the bioavailable tryptophan content actually present. Because of this, one would assume (comparing table values to requirement estimates) that lysine was first-limiting and tryptophan second-limiting in corn for the young pig. In fact, however, tryptophan is first-limiting and lysine second-limiting. The corn by-products, corn gluten meal, corn gluten feed and distillery by-products have been found to contain bioavailable tryptophan levels considerably below those estimated chemically.

FORMULATION OF DIETS ON AN AMINO ACID BASIS

It seems likely in the next 20 years that a combination of factors may surface which will result in increased usage of crystalline amino acids. Energy costs, for example, have risen and will continue to rise. If gasohol production continues to increase and if other fermentation residues continue to be produced in increasing quantity, demand for lysine and tryptophan (for supplementation of the by-product residue) will increase dramatically. Also, soybean prices will likely increase greatly, and this, too, will make it more difficult to justify heavy usage of this material in animal feeds. Breakthroughs are occurring and will continue to occur in amino acid production technology. Chemical synthesis of both tryptophan and threonine is being actively researched, and recombinant DNA technology offers hope that microbial synthesis of L-lysine might become considerably more efficient.

Protein vs. Amino Acid Formulation

Formulation of animal diets on an amino acid basis is therefore "coming into its own" so-to-speak. Unfortunately, nothing is ever as simple or as straightforward as we would like it to be. Thus, formulation of diets to a given level of crude protein using, primarily, grain and soybean meal has been easy and convenient. Moreover, several built-in safety factors may not be present if "amino acid formulation" *per se* becomes the accepted norm. Thus, formulation of diets to given levels of amino acids requires that the following conditions be met:

1. Knowledge of the requirement for each essential amino acid at each stage of the animal's life cycle.

2. Knowledge of all the factors that can affect the animal's individual amino acid requirements. For example, how exactly does age, weight, dietary protein and energy level, environmental temperature, breed, sex, propensity for lean vs. fat deposition and health status affect the individual amino acid requirements at each stage of animal production.

3. Knowledge of the essential amino acid content of each feed ingredient under consideration. The extent to which each feedstuff varies in its composition due to cropping and fertilization conditions, due to drying and/or processing procedures, (eg., cottonseed meal, blood meal) and due to the particular procedure (especially the hydrolysis method) selected to assay the amino acid(s) in question.

4. Knowledge of the bioavailability of each essential amino acid in each feed ingredient (at each processing state) considered for usage in the diet.

5. Knowledge of the metabolizable energy content of the diet used for each stage of production.

6. Knowledge of the "limits", i.e., the extent to which protein level *per se* can be ignored.

Certainly, those of us intimately involved in nutrition and feed formulation know the problems and limitations well. This should not preclude our striving to achieve total "amino acid formulation". But we should at the same time recognize and be willing to admit that it is, at present, far from a panacea. Thus, we do not have a good handle on amino acid requirements for certain ages of animals. Nor do we totally understand the quantitative relationships between those factors affecting the requirements and the requirements themselves. Nor do we feel comfortable with "table values" of amino acid composition, especially those for tryptophan and sulfur-containing amino acids. Nor do we have adequate bioavailability data on either pigs or chickens.

Lysine Formulation - An Example

Data in table 1 illustrate usage of crystalline lysine as a replacement for soybean meal-derived lysine for growing swine.

Table 1. Amino acid adequacy of swine grower diets formulated to 14 or 16% crude protein

Crude protein	Calculated lysine, %	Lysine requirement, %[a]	Other essential amino acids	Pounds of 44% soybean meal
16%	.77	.74	Adequate	420
14%	.63	.70[a]	Adequate	306

[a]It is a fact that the lysine requirement is related to the protein level in the diet. A protein reduction of one percentage unit results in a .02 percentage unit reduction in the lysine requirement.

In this example, changing from 16 to 14% crude protein resulted in the replacement of 114 pounds of soybean meal by corn in each ton of feed. Except for lysine, the 14% diet meets all essential nutrient requirements. The lysine deficiency in the 14% diet can be corrected in two ways: synthetic lysine can be added to meet the requirement or -- soybean meal can replace a portion of the corn to add extra lysine to the diet. Because pig performance will be identical in either case, the decision can be made strictly on the comparative costs of meeting the lysine need with soybean meal or synthetic lysine plus corn.

Consider synthetic lysine. It is produced industrially by fermentation and is typically marketed as L-lysine monohydrocholoride, more commonly called lysine·HCl. Commercial lysine·HCl is generally 78-79% pure L-lysine. To calculate the economic calue of this synthetic lysine, first establish the amount that is needed per ton of feed. The 14% diet contains .63% lysine while the requirement for lysine is .70%, a difference of .07 percentage units. This is equivalent to 1.4 pounds of pure lysine per ton of feed (2,000 pounds x .0007). Assuming the available source if 78% L-lysine then, 1.4 ÷ .78, or 1.8 pounds of synthetic lysine·HCl along with 112.2 pounds of corn could replace the 114 pounds of soybean meal. Obviously, the utility of synthetic lysine is dependent on the relative prices of soybean meal, corn and lysine. An example of the comparison that can be made is illustrated in table 2, and in this case there was a significant feed savings to be derived from using lysine.

Table 2. Comparison of synthetic lysine

Ingredient	Cost of ingredient	Cost per pound		Pounds needed	Total cost
Soybean meal	$210.00/ton	$ .105		114	$11.97
Corn	3.00/bu	.053	x	112.2	5.94
Lysine·HCl	2.50/lb	2.50	x	1.8	4.50
		Total cost of corn + lysine			$10.44

How much soybean meal can be replaced? Lysine can replace protein until a second amino acid becomes limiting. This point has not been well defined and is currently a subject of research in our laboratory and by others. In starter,

grower, and finisher diets a reduction of the crude protein by two percentage units below the recommended level seems justified. This is roughly equivalent to the replacement of 100 pounds of soybean meal in each ton of diet with 97½ pounds of corn and 2½ pounds of lysine·HCl.

Perhaps the most exciting potential use of lysine, today, is found in the supplementation of poor-quality protein sources such as cottonseed meal, peanut meal, sesame meal and sunflower meal. Each of these protein sources is very deficient in lysine but relatively adequate in other amino acids when fed in combination with cereal grains. The potential for use of supplemental lysine is well illustrated by dats extracted from a recent Texas A&M University experiment (table 3) in which pigs fed lysine-supplemented cottonseed meal gained as rapidly as those fed the standard sorghum-soy diet.

Table 3. Replacement of soybean meal by cottonseed meal + lysine on an available lysine basis

Pig response	Sorghum-soybean meal	Sorghum-cottonseed meal + lysine[a]
Daily gain, lb	1.65	1.65
Feed per pound of gain	3.78	3.87

[a]Iron sulfate added to prevent gossypol toxicity.

Cottonseed meal, sesame meal, peanut meal and sunflower meal each have unique problems that must be considered prior to their use, but there is little question that synthetic lysine greatly enhances their potential for use in swine feeding.

Nutritional Management of Growing Finishing Pigs

THOMAS J. HANRAHAN

Introduction

Pig production continues to be an industry concerned with converting feed ingredients into pigmeat with a degree of technical efficiency and economic management that allows a profit. While the profit motive remains unaltered as the stimulant to efficiency the methods employed to achieve it must be constantly reviewed. Technical developments and competition from other meat sources ensure that the level of efficiency demanded to remain viable is increasing each year. The basic principles of production remain unaltered, however pig feeds must be properly formulated and in the piggery feed must be efficiently converted to pig meat.

At farm level feed conversion efficiency (F.C.E.) is the most important criterion in evaluating pig performance. Successful enterprises will measure F.C.E. and have a clear understanding of the principal factors affecting it. These for the most part concern aspects of husbandry such as pig health, environment, ability and skills of the stockman. F.C.E. is also influenced by waste such as spillage or spoiling of feed within the piggery, dust loss and spillage from torn bags.

Small changes in F.C.E. are economically significant. For example an increase of 2.5% in the quantity of meal used reduces margin on a pig (birth to slaughter) by about 10%. F.C.E. can, and most likely will vary considerably within a farm with time or as the result of management decisions. This is demonstrated in Table 1 outlining data which refer to the same ration (formula) fed in different experiments at Moorepark. All took place in the same house with the same stocking density, system of feeding and over the liveweight range 30-82 kg. Feed intake varied considerably but was the stockmans interpretation of "feeding twice daily to appetite".

Table 1. Variation in F.C.E. of pigs fed the Moorepark Reference ration in different experiments in the same piggery (5 pigs/pen)

Period	1976-78			
Expt. No.	90	94	86	106
Daily feed intake kg	2.28	2.15	2.12	2.06
F.C.E.	3.07	2.99	2.91	2.78

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Before discussing aspects that are important in achieving a good F.C.E. it may be interesting to consider the figure currently being achieved. Data from the University of Cambridge Pig Management and M.L.C. Pig Feed Recording schemes in the U.K. indicate that F.C.E. improved from 3.6 in 1976 to 3.3 in 1980. For the better 30 % of units F.C.E. was 3.2 (1980). The rations fed would most likely contain 3 to 3.1 Mcal DE/kg. In Ireland dairy by-products (skim milk and whey) make up to 10% of pig feed, otherwise rations contain approximately 3 Mcal DE per kg. F.C.E. on commercial units averages 3.4. In 1971 the figure was 3.8 (1).

Technically there are no barriers to achieving an F.C.E. of 3 or better over the liveweight range 30 to 82 kg. This is borne out by the performance achieved on the reference ration at Moorepark over the past 5 years (Table 2). This ration although well balanced had no more than 3 Mcal DE/kg. The house is similar in design to many found on commercial farms having 40 pens of 16 pigs in

Table 2. Performance of pigs in a commercial type house at Moorepark (16 pigs/pen)

Expt. No.	Year	Daily feed intake kg	F.C.E.
91	1976	2.10	3.22
96	1977	2.13	3.09
104	1978	2.16	3.12
108	1979	2.18	3.15
110	1980	2.15	3.15
121	1981	1.90	2.89

a single naturally ventilated room. The worst performance was obtained in the first year of operation - 1976. The improved F.C.E. in the current year has to be associated with a change from meal to pellet feeding and possibly greater feed restriction. Important factors affecting F.C.E. are discussed as follows:

Nutrition

The nutrient requirements of pigs for the maintenance of health and normal development are defined (2,3) to an extent that the existence of unknown growth substance is losing credibility (4). In commercial pig production one has to differentiate between the requirements for health and that which allows optimum performance as measured by profitability. The situation most commonly encountered is one of giving nutrient allowances above the minimum specification with a view to maximising economic returns. However since feed costs are so large one has to be extremely careful to ensure that returns justify the extra cost. Experience has shown that digestible energy and lysine are the most expensive nutrients and hence most likely to affect profit.

Energy level or feed level

The ingredients used for pig feeds in the Mid West States namely maize and soyabean meal when properly blended and fortified with minerals and vitamins, can provide the near ideal ration for pigs (5). Perhaps the only disadvantage of such a ration is that it is too nutritious for finishing pigs. The energy content of 3.3 to 3.4 Mcal DE/kg is high resulting in the production of fat carcasses and an inefficient conversion of feed energy to pigmeat. This effect of high energy rations is demonstrated in Table 3 from an experiment undertaken by Cook et al (6) at the University of Nottingham. The most efficient carcass gain or fat free gain was obtained with an energy level of 3.1 Mcal/kg. Most

Table 3. Effect of energy level on efficiency of tissue deposition in pigs (23-59 kg liveweight)

Energy level Mcal DE/kg	2.83	3.11	3.38	3.59
Feed/day kg	1.64	1.63	1.63	1.62
Carcass gain/day g	512	577	590	598
Fat free gain/day g	359	389	386	384
Fat gain/day g	101	129	147	159
Cal/g carcass gain	9.1	8.8	9.3	9.7
Cal/g fat free gain	12.9	13.0	14.3	15.2
Cal/g fat gain	45.9	39.3	37.5	36.6

efficient fat deposition occurred at the highest energy level. These results clearly demonstrate that rations containing 3.3 Mcal DE/kg or greater can more than meet the pigs energy demand and will result in the production of pigmeat with a high fat content.

A similar effect can be obtained with rations containing lower energy levels by varying the quantity of meal fed. For example pigs fed ad libitum on rations containing 3.0 Mcal DE/kg are capable of consuming more energy than they require. The excess energy is deposited in the carcass as fat, resulting in a deterioration in F.C.E. This is shown in Table 4 outlining the results of an experiment by Verstegen (7) where the quantity of feed allocated varied from ad libitum to severe restriction. Restricting feed intake to 85-80% of ad libitum intake results in an improvement in F.C.E. Where restriction is carried beyond this level F.C.E. deteriorates because of the increasing proportion of feed used for maintenance.

Table 4. Effect of feed intake on F.C.E. (wt range 37-103 kg ration 3.15 Mcal DE/kg)

		% of ad lib		
	Ad libitum	86	74	65
Feed intake kg	3.01	2.66	2.29	2.04
Daily gain g	999	879	749	619
F.C.E.	3.10	3.04	3.07	3.33

Summarising the literature upto 1967 Vanschoubroek et al (8) calculated that a feed restriction of 15.8% of ad libitum intake reduced daily gain by 12.5% and improved feed conversion efficiency by 3.96%. Backfat thickness was reduced by 7.63%. The greater response to restriction reported by the latter is most likely to relate to a definition of ad libitum feeding which under many situations involves an element of feed wastage. Thus recorded feed intakes need not necessarily mean actual feed consumed. This is demonstrated by the results of 2 recent experiments from Moorepark where pigs were penned in groups of 16 and fed from a hopper type feeder. Experiment 1 compared 6 versus 24 hour access to the feeder and experiment 2 compared 6 hour access to either meal or pellets. The pellets were formulated similar to the meal but were shown to contain 1% less D.E. due to a higher moisture content. The results are presented in Table 5.

Table 5. Effect of 24 hour versus 6 hour access to feed and meal versus pellets

	Expt. 1			Expt. 2		
	24 hr access	6 hr access	F test	6 hr meal	6 hr pellets	F test
No. of pigs	640	640		192	192	
Daily feed intake kg	2.47	2.13	***	2.16	2.20	NS
Daily carcass gain g	595	552	***	558	601	***
Feed/kg carcass	4.16	3.87	***	3.87	3.67	*
Meat in leg %	70.3	70.5	N.S.			
Fat in leg %	20.2	19.9	N.S.			

The ad libitum fed pigs consumed 16% more feed and had 7% worse F.C.E. than those restricted to 6 hr feeding. This deterioration in F.C.E. is greater than reported in the literature and cannot be explained by increased deposition of carcass fat which was insignificant (indicated by a leg dissection of 25% of pigs on each treatment). That the more recent experiment 2 in the same house showed a 5% improvement in F.C.E. with pelleted feed confirms feed wastage. To conclude that feed wastage from hopper type feeders can be very significant is easy. To avoid it in practical situations may be difficult. Where the number of pigs per pen is large excessive feed restriction results in more aggression during feeding and may lead to tail-biting. With many proprietary dry feeding systems it is possible to restrict the quantity of meal delivered to a feed hopper so that feed restriction may be practiced. In such a system the feed hopper empties daily preventing a build up of mite infestation which if it occurred would reduce F.C.E. (9).

Lysine level

The lysine level in a maize-soyabean diet at 0.75% adequately meets the pigs requirements. Both the A.R.C. and N.R.C. recommend such a level eventhough there is some published evidence suggesting higher levels. My own experience agrees with the former in that I got no response above a level of 0.74% with a

ration containing 3.1 Mcal DE/kg. (Table 6).

Table 6. Effect of lysine level on pig performance

Lysine level %	.69	.74	.79	.86	.90	
Daily feed intake kg	2.06	2.04	2.10	2.06	2.08	N.S.
Daily carcass gain g	518	538	537	545	548	N.S.
Feed/kg carcass	3.98	3.81	3.93	3.74	3.83	**
Av. backfat mm	27	27	27	27	27	N.S.

Environment

Piggeries must be well maintained and above all must have good insulation and control over the ventilation system. This is necessary to maintain the critical temperature zone within which pigs are comfortable and where they will perform best. Above or below this temperature zone a pig is stressed and F.C.E. deteriorates. For fattening pigs we are mostly concerned with temperature below the critical where the average reduction in growth rate is 16.2 g/day/^{o}C, with a corresponding depression in F.C.E. of 0.085 (10). The critical temperature for pigs is shown in Table 7. These data are calculated (11) assuming no draughts, a dry well insulated floor; a meal to water ratio of 1:4 and 16 pigs per pen. A draughty house (air velocity 0.6 m/sec) will have a critical temperature 4°C higher than the table figures while with a wet floor the figures will be raised 5 to 10°C depending on how wet the pigs become (12).

Table 7. Critical temperature for pigs 30 to 80 kg

Weight kg	Feed intake/day kg	Critical temperature ^{o}C Min.	Max.
30	1.4	14.4	27.6
40	1.64	14.0	27.6
50	2.0	12.6	27.1
60	2.26	12.2	27.1
70	2.5	11.9	27.1

In practice it is advisable to record temperature daily and to keep the minimum temperature (thermometer reading) above 20°C. This will counter minor draughts or wetness of floors.

Stocking rate

For pigs in the weight range 30 to 82 kg liveweight irrespective of floor type the optimum space allowance appears to be 0.65 m^{2} per pig (13). A higher stocking density subjects pigs to stress which manifests itself in lower feed intake and a deterioration in F.C.E. This is demonstrated in Table 8 showing data from an experiment undertaken at Moorepark.

Table 8. Effect of stocking rate on pig performance

Floor area per pig m^2	0.64	0.57
No. of pigs/treatment	640	720
No. of pigs/pen	16	18
Daily feed intake kg	2.15	2.09
Daily gain g	686	649
F.C.E.	3.15	3.23
Average backfat mm	27.4	27.1

There are few experiments pertaining to the effect of group size on performance especially for groups in excess of 20. Group size and stocking rate cannot be discussed in isolation, they are influenced by feed level, feeding system, house temperature, floor design etc. The bulk of evidence however points to the fact that pigs perform best in small groups (13).

Effect of sex and slaughter weight

F.C.E. improves in the order castrates, gilts and boars. A difference of 8% was recorded between boars and castrates with restricted feeding at Moorepark (Table 9). Dutch results (14) suggest that with ad libitum feeding the difference will approach 10%. Boar carcasses are much leaner and this trait is ranked so highly by consumers that it offsets an adverse response to the slight taint associated with a small percentage of boar carcasse (15).

Table 9. Comparison of boars and castrates (33-85 kg liveweight)

	Castrates	Boars	F-test
Daily feed intake kg	2.18	2.14	N.S.
Daily carcass gain g	582	619	*
Feed/kg carcass	3.76	3.47	***
Average backfat mm	28	25	***

Within the fattening interval (30 kg to slaughter) incremental increases in slaughter weight of 9 kg were found to increase F.C.E. by 0.15 (16). However if the sows feed plus the feed consumed upto 30 kg is taken into account then it matters little whether pigs are slaughtered at 64 kg or 100 kg liveweight as shown in Table 10.

Table 10. Effect of slaughter weight on F.C.E. - birth to slaughter including sow feed

Slaughter wt. kg liveweight	Feed/kg carcass assuming 16 or 18 pigs/sow/year	
55	5.13	4.92
64	4.97	4.79
73	4.97	4.82
82	4.98	4.85
91	4.94	4.82
100	4.98	4.87
109	5.05	4.95
118	5.12	5.03

Increasing sow output from 16 to 18 pigs is far more significant in that it improves F.C.E. by about 3%. If the boar advantage over castrate is expressed in terms of total feed per kg carcass gain the improvement is also about 3%.

Summary

1. F.C.E. is the most important criterion in evaluating pig performance at farm level.

2. Experience at Moorepark suggests that variations in feed allowance per pig is a prime cause of variations in F.C.E.

3. Maximum growth rate can be achieved using rations considerably lower in D.E. than maize soya rations.

4. Ad libitum feeding leads to lowered F.C.E., fatter carcasses and in many situations considerable feed wastage.

5. Moderate feed restriction improves F.C.E. and carcass quality. In a practical situation with feed available from hoppers for 6 hr rather than 24 hr daily F.C.E. was improved by 7%. Using pelleted feed rather than meal gave a further improvement of 5%.

6. Lysine levels higher than 0.74% do not appear to benefit pig performance.

7. Pigs perform best within the critical temperature zone and when not overstocked in large groups.

8. Boars outperform castrates by about 10% on F.C.E. over the growing-finishing period. If sow feed plus feed over the entire growing period is taken into account F.C.E. is scarcely affected whether pigs are slaughtered at 64 or 100 kg.

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Biologic Efficiency and Pork Profits

T.D. TANKSLEY, JR.

First, let's place things in perspective. Pig performance, from birth to market, is determined primarily by *genetics, nutrition, environment, and health.* These same things also affect reproductive efficiency (pigs/sow/year) but management and facilities assume greater importance. Perhaps this is an oversimplification, but it provides a starting point and the boundaries for our discussion.

A sound management program should give consideration to each of these production-limiting factors in order to *optimize performance at the lowest possible cost.* If this is accomplished, profits are maximized. The one criterion most widely used to measure production efficiency and profit is efficiency of feed utilization. Although it has shortcomings, this is a good yardstick and one that should be determined by every pork producer. It can be easily obtained by dividing the total pounds of feed fed to *all swine on the farm* by the total pounds of *all swine sold.*

Since feed efficiency reflects the level of efficiency in all production phases, producers have many opportunities to improve management procedures to give improved feed efficiency. For simplicity, our discussion concerning the opportunities for improving feed efficiency will be focused in the three following areas.

I. Applying More Pressure on Recognized, Economically-Proven Practices
II. Identifying and Attacking the Major Weaknesses
III. Future Possibilities Through Research

Time limitations prevent our going into detail in each area but, hopefully, we can identify some opportunities.

I. APPLYING MORE PRESSURE ON RECOGNIZED, ECONOMICALLY-PROVEN PRACTICES

Several avenues for improving efficiency have been identified and are well-recognized by producers. The economic importance of each is documented and every producer is challenged to review his management procedures to make sure he is doing everything possible to give improved efficiency. Some of the most important practices include:

1. Improved reproductive efficiency (more pigs/sow/year).

Gained through higher conception and farrowing rates, more pigs

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farrowed & weaned, faster rebreeding, increased survival during nursery and growing-finishing phases.

2. Use of *LEAST COST PERFORMANCE* diets.

   Diets and feeding program should optimize pig performance, feed and fixed costs.

3. Keep pigs comfortable.

   Environments below the lower critical temperature or above the upper critical temperature force the pig to use a higher percentage of feed for maintaining body temperature or for maintenance which leaves less available for body gain.

4. Reduce feed wastage.

   Poor feeder design and/or improper adjustment can cause feed wastage up to 25%.

5. Sound, well-planned herd health program.

   a. "Closed herd" concept
   b. "All in-all out" of buildings
   c. Strict isolation & retesting procedures for incoming breeding animals
   d. Effective immunization & sanitation programs
   e. Control of internal & external parasites

6. Market at reasonable weights (210-240 lb).

   The energy cost per unit of fat deposition is usually over 3X that for lean, therefore, the feed/gain ratio increases rapidly as pigs reach heavier weights.

7. Use growth promotants wisely.

   The positive response to growth promotants is greatest during the nursery phase. Response diminishes as weight increases. Addition of growth promotants during the growing-finishing phase must be carefully evaluated on a cost-benefit ratio. Your on-the-farm tests are the most reliable indicators of the economics of their use. However, as feed costs rise, the economic advantage from growth promotants is increased.

II. IDENTIFYING AND ATTACKING THE MAJOR WEAKNESSES

It was an astute man who said "Attempting to make management decisions in a swine operation without records is like attempting to steer a ship without a rudder". Records have always been important but as production units become larger and more complex, they are an absolute necessity to accurately identify the "weak spots" that limit profits. The advent of micro-computers and the development of effective software provides an opportunity to identify weaknesses rapidly so they can be attacked in an organized, systematic manner.

Unfortunately, I know of several micro-computers and programs that are collecting dust because there were no software programs or the program used failed to present the reports and summaries in a usable form. An effective computer system must have a well-organized system of collecting the data needed to give the summaries desired, and the summaries must be presented in a format

that "speaks" to tell us what we need to know.

As software for hog production records is developed and refined, effective computer service will be available to all producers through on-farm computers, local computer banks, or through regional, state or nationwide record keeping services. There are advantages and disadvantages to each system -- each producer must select the system that gives him the records he desires for the least cost. The type and amount of information desired from the computer must be decided by each producer -- the more summaries desired; the more data that must be placed in the computer. It appears that the following print-outs are needed (as a minimum) to accurately identify "weak spots" that need attention. Although suggested performance levels are indicated, these are only guidelines -- the levels for a specific farm will be greatly influenced by facilities, herd health and the management scheme.

	Desired Performance Levels
1. No. sows bred/group	
2. No. sows that heat-checked positive/group	
a. Conception rate, %	
(1) Sows	> 90.0
(2) Gilts	> 85.0
3. Sows farrowing/group	
a. Farrowing rate, %	
(1) Mature herds	> 85.0
(2) Gilt herds	> 80.0
4. Pigs born/litter	
a. Total	> 11.0
b. Alive	> 10.0
c. Stillbirths	< 1.0
d. Mummies	< .25
5. Pigs weaned/litter	
a. Sow herd	> 8.5
b. Gilt herd	> 8.0
6. Avg. weight at weaning (28 days), lb.	> 14.0
7. Nursery	
a. No. out	
b. Avg. wt. out @ 63 days of age, lb.	> 45.0
8. Growing-Finishing	
a. No. out	
b. Avg. wt. out	
c. Age at market, days	< 180
9. Death loss, %	
a. Weaned/live pigs farrowed	< 10.0
b. Nursery	< 2.5
c. Growing-finishing	< 1.0

10. Inventory

    a. No. sows
    b. No. gilts
    c. No. boars

These data, which can be summarized by sow group or for any specific time period, provide sufficient information to enable a manager to identify the "soft spots" that need attention. For example, every farrowing crate must be filled at each farrowing to maximize efficiency and profits. If houses are not full, one can check quickly the number bred, number that heat-checked positive and number farrowing to evaluate the job being done in breeding, in heat-checking or the presence of viral infections that may be reducing farrowing rate (especially in gilts).

These data do not include feed summaries for each phase of production because of the difficulties in obtaining them. However, the input data must include the feed used during a specific time period so that efficiency can be determined for that specific time period. Ideally, feed records for each sow group would be obtained as they move through the production phases which would enable feed efficiencies to be determined during each phase of production -- and it may be necessary to do this in solving a specific problem, but the yearly summary probably provides the most accurate and practical measure. Many obtain weekly or monthly feed efficiency summaries but they often fluctuate widely because of increased or decreased farrowings and marketings.

The yearly value is determined by dividing the pounds of feed required for the entire operation by the pounds of all live hogs sold. An arbitrary ranking of efficiency values might be:

3.25 or less ---- Outstanding, but possible

3.25 to 3.50 ---- Excellent

3.50 to 3.75 ---- Good

3.75 to 4.00 ---- Fair

Over 4.00 ---- Needs attention

III. FUTURE POSSIBILITIES THROUGH RESEARCH

This is the exciting area because of the potential. I would like to discuss four possibilities that have not been adequately demonstrated or researched at this time to evaluate their potential. Unfortunately, there are no easy ways to evaluate these possibilities. All will require dedicated scientists and time-consuming, high-investment research. I challenge you to evaluate these possibilities and to work closely with your researchers in planning long-range programs and in providing the financial support needed.

1. Improved Digestibility of Nutrients in Feedstuffs, Particularly Amino Acids and Energy.

All the protein and energy in feedstuffs, as determined by chemical means and calorimetry, are not biologically available to the pig. The proportion of protein intake lost in the feces may range from 5 to 25% depending on the feedstuffs used; the amount of dietary energy lost is

generally lower and more uniform (normally 5 to 15%). These values indicate the magnitude of improvement possible.

Amino acid digestibility has received increasing importance in recent years for two reasons. First, because of its importance in diet formulation (diets are generally balanced to meet the requirements for the first limiting amino acid) and secondly, because recent research has shown that the amino acids digested in the large intestine are essentially useless to the pig for protein synthesis. Infusion experiments have demonstrated that the nitrogen from amino acids digested in the hind gut is absorbed as ammonia or amines and excreted in the urine. In contrast, the energy digested in the large intestine is absorbed as volatile fatty acids which can be used for energy. Although VFAs are not used as efficiently as glucose for energy by the pig, the loss in efficiency is probably only 20 to 25%.

Because the protein entering the large intestine is of little value to the pig, several European and Canadian workers, as well as our laboratory, have attempted to measure amino acid digestibility at the end of the small intestine before the digesta enters the hind gut. This should accurately reflect what was actually available for use by the pig. Digesta is easily collected through a simple T-cannula placed at the end of the small intestine. The Texas A&M group has determined amino acid digestibilities in 5 grains and 11 high-protein feedstuffs in the last 4 years. Feeding trials are in progress to determine the usefulness and validity of these values in formulating practical swine diets.

Digestibility of amino acids in all feedstuffs tend to be lower measured at the end of the small intestine than over the total tract. Interestingly, the first three limiting amino acids in grain-soybean meal diets (lysine, tryptophan and threonine) usually have the lowest digestibility coefficients among the essential amino acids measured at the end of the small intestine. For example, lysine digestibilities ranged from 60.5% (meat & bone meal) to 88.5% (soybean meal), tryptophan from 57.4% (meat & bone meal) to 83.1% (glandless cottonseed meal) and threonine from 50.0% (meat & bone meal) to 78.5% (glandless cottonseed meal). This wide range in content suggests that using these values provides an opportunity to make substitutions of low-quality, high-protein feedstuffs for soybean meal in practical diets and obtain similar pig performance and enable one to provide the minimum requirements more precisely and economically. However, more research is needed to determine the practicality, merit and economic potential of using these values in formulating practical diets.

2. Reduced Protein Turnover in Tissue

We must realize that "laying down protein" in the body is not like "laying down concrete". Muscle and all the body organs are metabolically active tissue. It has been clearly demonstrated that protein in most body organs are continually being synthesized and degraded. Waterlow *et al.* (1978) suggests that the balance between the rate of protein synthesis and degradation is one of the major controlling factors of protein deposition. Although the amount of protein which is synthesized and broken down daily eventually becomes equal when the animal ceases to grow, it is not known whether changes in the rate of protein deposition during growth arise

primarily from changes in protein synthesis, in breakdown, or in both or if there is a fixed relationship of one to the other. A 1980 report by Reeds *et al.* provides good data on the relationship between protein deposition and protein synthesis. When protein synthesis and protein deposition were altered by varying food intake at a fixed body weight, each unit increase in protein deposition was associated with an increase of 2.17 units in total protein synthesis and therefore, presumably an increase of 1.17 units in the breakdown of body protein. Efficiency of protein deposition may be expressed as the proportion of total protein synthesis which is deposited. As animals grow larger, efficiency of protein deposition decreases.

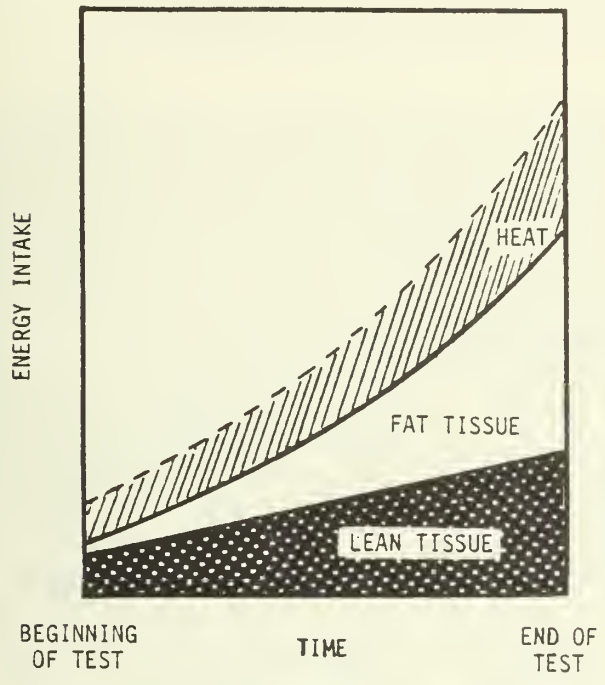
Kielanowski (1976) suggested that heat production (lost energy) in an animal is clearly related to protein deposition. This has been taken to imply that the process of protein deposition is energetically inefficient. The fact that protein synthesis greatly exceeds protein deposition and requires a considerable input of energy for peptide bond formation has been suggested as the reason for the apparently high energy cost of protein deposition.

While much is known about the factors controlling protein synthesis, (e.g. amino acid supply and availability of messenger RNA), much less is known about the factors controlling degradation. The ultimate limits to protein utilization are set by how much protein the pig will eat and by how rapidly it can synthesize body protein without simultaneously breaking it down. A better understanding of this control may allow new approaches to selection of breeding animals. Undoubtedly, there are differences among the swine population in their ability to synthesize protein at an accelerated rate with less degradation. The industry needs a practical and accurate way to measure these differences in animals. The diet that is provided, especially the quality of protein, may influence rate of synthesis and degradation. The possibility of altering the protein synthesis to protein deposition appears good. More research effort is needed to find the answers.

3. Controlled Feeding to Reduce Energy Intake

In the growing pig, part of the feed energy is deposited as protein and fat. An increase in the energy supply increases both fat and protein deposition, but fat deposition increases at a faster rate, especially at higher energy levels. Feed intake is often so high that more feed is eaten than is required to maximize protein deposition. From an efficiency standpoint, there is an optimal energy supply needed per day for a pig to maximize muscle development but deposit just enough fat to give the desired lean quality. It appears that the ability of a pig to deposit protein (both the rate and the total amount) is affected primarily by genetics. In contrast, the main factor which limits fat deposition is energy intake. Sure, breeding causes some animals to be more prone to fatness but the degree of fatness can be reduced by controlling energy intake.

The graph below shows the theoretical partition of metabolizable energy in the growing pig. It suggests that one of the best opportunities for improving feed utilization is to provide enough dietary energy to maximize protein deposition and a small additional amount to obtain the degree of fatness required to give quality to the pork cuts. This was demonstrated in a recent study by Metz *et al.* (1980) who fed two levels of energy intake at adequate protein intakes. Restriction of the daily energy intake by 20% resulted in 15% lower live weight gains, 8% lower carcass muscle weight and 28% less carcass fat. The difference in growth rate was much less than the difference in metabolizable energy available for growth due to a lower energy content of the weight gain in pigs fed the lower daily quantity of energy.



The decrease in carcass muscle growth by 8% means that the efficiency of converting feed to carcass muscle was increased by about 15% by decreasing the daily energy supply by 20%. This is an important observation and emphasizes that further quantification of the relationship between energy supply and muscle growth is necessary in order to select the right feeding regime for lean meat production. Certainly this is affected by the genetic capacity of the pig for protein deposition. It seems reasonable to assume that the decrease in protein deposition due to a restriction in energy intake would be greater in pigs with a higher genetic capacity for protein deposition.

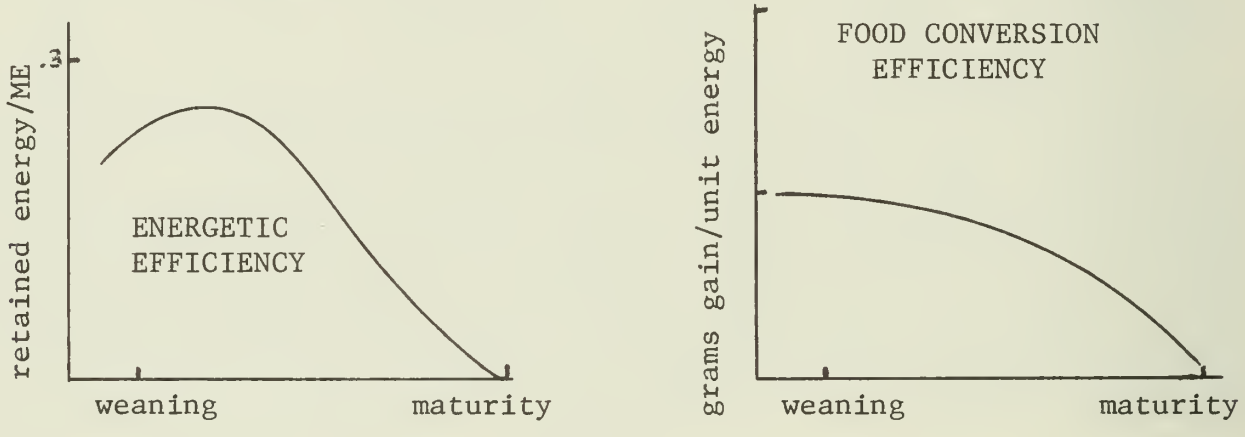
One must acknowledge that limit feeding was tried in the United States 15 to 20 years ago and it lost favor because our pens and equipment were not designed for it and producers received no higher price for the leaner carcass. But that was when energy was cheap -- today we have a different set of economic conditions. Well-defined studies are needed to determine the effect of energy intake on gains, feed efficiency and carcass composition. In order to obtain the composition of the weight gain accurately, it is necessary to dissect pig carcasses into their anatomical parts and analyze the chemical composition of each of these parts. Only a few workers have done this, but it is mandatory to obtain the correct answers in this important area. In the future, we must concern ourselves more with the amount of acceptable lean meat produced in relation to the metabolizable energy and amino acids fed.

4. Increased Mature Size of Breeding Stock?

Many European scientists suggest that the efficiency with which the growing pig converts its food into pork is determined overwhelmingly by the efficiency with which it uses energy, the major nutrient in a feedstuff. Many research projects are underway in an effort to find ways to

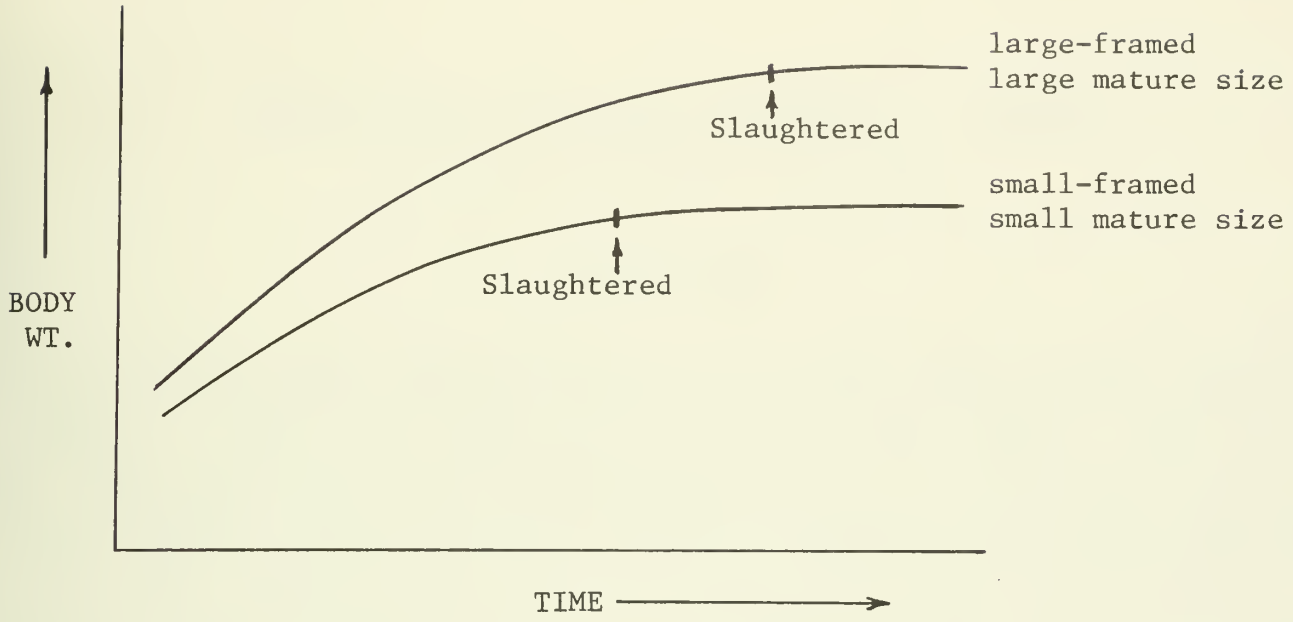
get a higher percentage of the metabolizable energy (the energy remaining after subtracting that lost in feces and urine) deposited as protein and fat and less to be lost as heat production. One excellent paper discussing the energetic efficiency of growth was published by Webster in 1980.

Regardless of the breeding of an animal, body weight and other things such as lean mass, body fat and metabolic rate increase from the time of conception along a curved line that plateaus as the animal reaches maturity. The effect of this fundamental law of growth on the efficiency of utilization of metabolizable energy by a pig as it proceeds from weaning to maturity is shown by the illustration below (left). The overall efficeincy of energy retention reaches a peak at about 25% of mature body weight and declines steeply thereafter. Also, as an animal matures, the ratio of fat to protein in body gains increases. The energy content of lean meat is about 1.15 kcal/gram and for fat it is about 9.33 kcal/gram. Feed conversion efficiency, which reflects both the ability of the animal to retain energy in relation to metabolizable energy in the feed and the energy content of body gains, is relatively constant during the first third of growth and then begins to decline steeply at about 30% of mature size, as illustrated below (right).



What does this mean? What is its significance as we attempt to select hogs with improved feed efficiency? These fundamental laws of energy utilization show that maturity has a profound effect on the energetic efficiency of growth. *If animals are fed to a fixed body weight and selected for growth rate, leanness or feed efficiency, it will nearly always favor the animal that is less mature, therefore we are essentially selecting for increased mature body size.* Recent studies have indicated that animals with wide variations in frame size (mature body weight) -- who would express significant differences in leanness, percent fat and feed efficiency if fed to a common endpoint (240 pounds, for example) -- *exhibit essentially no differences in carcass leanness or feed efficiency if both are slaughtered at the same relative position on their growth curve, as indicated on the following page.*

GROWTH CURVE FOR LARGE AND SMALL-FRAMED PIGS



This enables one to understand better the relationship between the amount of fat on an animal and feed efficiency. Because the energy density of fat is about 8 times that of lean meat, it is often assumed that the leaner animal is automatically the more efficient converter of feed. *If the animal is leaner because it is less mature, then the association is valid.* Comparisons made, however, at a similar degree of maturity reveal no clear association between leanness and efficiency of growth.

What feed conversion advantage would a commercial producer realize if his sows and boars had the genetic capacity to be 100 pounds heavier at maturity than his present herd if he marketed his pigs at 230 pounds? The heavier sow will have a higher maintenance requirement but the growth curve of the pigs will be extended. Undoubtedly there is a mature size of breeding animal that maximizes feed efficiency for a specific production program. Variables such as the nutrition and feeding program, and marketing weight may hinder attempts to be very specific.

I don't pretend to know which of these five possibilities will have the "biggest payoff" to the industry but we need well-defined studies to determine their value.

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Alternative Energy Feedstuffs for Swine

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INTRODUCTION

In a recent report, Pond (1981) noted that "the survival of the livestock industry of the future, including the swine industry, will depend on the ability of animals to compete with humans for the available food supply." Over the years, cereal grain production has increased markedly and has provided a relatively cheap and abundant supply of energy feedstuffs for both ruminant and non-ruminant animals. However, as these energy feedstuffs increase in demand for direct human use, alternative energy feedstuffs will be used increasingly for livestock production. Such feeds include forages and fibrous by-products normally used in ruminant feeding. In this article, we will examine some of the recent developments related to the use of alternative energy feedstuffs by swine and which may have an impact on the future feeding practices used in the swine industry.

CHEMICAL AND PHYSICAL PROPERTIES OF ALTERNATIVE ENERGY FEEDSTUFFS

A general property of most alternative energy feedstuffs is their higher fiber content compared with that of traditional energy feedstuffs. It is this greater fiber content that we must deal with if we hope to maximize utilization of such materials. Dietary fiber is the insoluble structural matter of plants that is resistant to animal digestive enzymes (Van Soest and Robertson, 1976). The term "non-nutritive" is often applied to the groups of substances resistant to animal digestive enzymes, but the use of this term ignores the fact that fibrous carbohydrates may be nutritionally available through fermentation and contribute significant digestible energy to non-ruminant animals. Also, fiber may contribute in a nutritionally beneficial way by influencing transit of feed and the environment of the lower digestive tract.

Chemical Properties

Plant substances can be divided into two groups: one fraction, often termed "cell solubles" and generally completely digestible by animals, is active in plant metabolism, respiration and growth and includes nucleic acids, sugars, storage carbohydrates, protein and lipids, all of which are metabolizable by animals (Van Soest, 1977). The other category is the structural matter forming the cell wall of the plant. Animal digestive enzymes to degrade these structural substances have not evolved. On the other hand, some bacteria and fungi have

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enzymes to degrade most of the substances in the plant cell wall (Gibson, 1968). The use of structural matter as feed for animals is dependent upon a symbiotic association with gastrointestinal organisms with the requisite ability to degrade plant structural matter (Hungate, 1966).

Resistance to digestion arises from several features of the chemical structure. Linkages resistant to animal enzymes allow for the possibility of microbial fermentation (Table 1). Microbial enzymes exist that will hydrolyze most

Table 1. Availability of plant fractions to animal enzymes

Substance	Linkage	Sugar Components	Nutritive Property[a]
sucrose	1-2	glucose and fructose	digestible
starch	1-4	glucose	digestible
pectin	mixed	galactose, galacturonic acid and arabinose	resistant but fermentable
cellulose	1-4 cross chain hydrogen bonds	glucose	resistant but fermentable
hemicellulose	varied and linked to lignin	xylose, arabinose mannose and glucuronic acid	resistant but partly fermentable
lignin	condensed	none	resistant to animal and anaerobic digestion systems

[a]Availability to animal digestive enzymes. Van Soest (1977)

glycosidic linkages occurring in plant cell walls (Wood, 1970). Polysaccharides will be fermented provided that the bond is accessible to attack. However, very crystalline celluloses (e.g., cotton,straw) may remain undigested because of the intensive crosslinking of chains through hydrogen bonding. The maximal rate of cellulose digestion varies an order of magnitude between various sources (Table 2). It is for this reason that the determination of only cellulose as a feed characteristic is a relatively useless endeavor in the effort to evaluate feedstuffs of plant origin. The cellulose fractions of various plant sources vary in nutritive quality through their intrinsic characteristics, as well as that of their association with other plant carbohydrates.

The non-cellulosic carbohydrates of the cell wall include primarily the hemicelluloses. These are a diverse group of sugars and may contain residues of xylans, uronides, arabans, galactans and mannans. Hemicellulose is also incompletely digestible. In ruminants, digestibility is closely related to that of cellulose in the same plant source. In non-ruminants, hemicellulose is relatively more digestible than cellulose.

Lignin is the main non-carbohydrate component of plant fiber. It is an aromatic polymer containing continuous carbon to carbon linkages which are very resistant to hydrolysis. Degradation of lignin in the digestive tract is limited by the absence of oxygen in the cellulolytic fermentation and no significant degradation of the core molecule occurs (Gibson, 1968).

Table 2. Fermentability by microorganisms of plant fibers

Fiber Source	Fermentation			15 h digestion coefficient
	Lag[a]	Rate[b]	Maximal extent[c]	
	h	%/h	%	%
Cauliflower	4	42	94	93
Corn bran	5	10	94	54
Wheat bran	3	6	43	33
Alfalfa	4	12	59	32
Bagasse	4	4	45	23
Cotton	17	4	98	18

Van Soest (1977)

[a]Lag determined by the zero intercept of the regression of log residual fermentable fiber against time.

[b]Regression slope of natural log of residual fermentable fiber upon time.

[c]Maximal digestion at 72-100 h.

Although still in common use today, the crude fiber method of feedstuff analysis is unable to differentiate between nutritionally available and unavailable plant fractions. In approximately 30% of the tabular values of feedstuffs, crude fiber is as digestible as the nitrogen-free extract, even though the main purpose of their division was to separate the unavailable from the available nutrients. The principal fractions that are not recovered in crude fiber are hemicelluloses and lignin. An alternate method which is far superior to the crude fiber method has been developed by Goering and Van Soest (1970). Using this method, a more accurate assessment of plant fiber content of feedstuffs can be obtained. A fractionation scheme using detergents is used to isolate specific fiber fractions (Table 3).

Table 3. Scheme of fractionation of plant feedstuffs with detergents

Fraction	Organic Components
Cell contents	protein, sugars, starch, lipids, pectin, gums
Neutral detergent fiber residue (NDR)	lignin, cellulose, hemicellulose, cell wall protein
Acid detergent solubles	hemicellulose, some cell wall protein
Acid detergent fiber residue (ADR)	lignin, cutin, cellulose, heat damaged protein
Crude lignin	lignin, cutin, heat damaged protein
Crude cellulose	cellulose, cutin

Goering and Van Soest (1970)

Physical Properties

The physical properties of dietary fiber have received little attention but considerable evidence has been presented indicating that physical factors are important (Van Soest and Robertson, 1976). The principal properties that have received some attention are particle size, density, hydration capacity and ion exchange capacity.

Particle size. Van Soest (1977) proposed the "hotel theory" to explain the importance of particle size to the utilization of plant fiber. Structural plant fiber encases nutrients within plant cells. The entrances through which plant nutrients are transported become the route of access to animal and microbial enzymes when the dead plant becomes food. The structure of the plant fiber being digested may be compared to a large hotel in the process of being demolished. Considerable weight of the structure can be removed without altering its inherent volume unless previous treatment through milling or mastication crushes portions of the structure. Also, in highly digestible fibers, fermenting bacteria may digest connecting parts and promote collapse. The only mechanism for reducing volume of the structure is crushing or grinding or other processes that may reduce particle size (Table 4). Finer grinding may increase the likelihood that

Table 4. Influence of grinding on bulk volume of wheat bran fiber

Ground to Pass, mesh	Bulk Volume, ml/g
10	7.4
20	6.2
40	4.6
60	3.7

Van Soest (1976)

fiber particles will flow with the liquid portion of the digesta whereas coarser fiber will tend to mat and flow with the solid portion of the digesta. Finely ground fiber can pack more densely and therefore has a reduced bulk effect. These effects become the mechanisms for differential passage of residues through the digestive tract.

Density. Since plant fiber is the skeleton and covering of the plant in which are contained all of the nutrients, it follows that plant fiber or cell wall determines the volume of the structure. Baker *et al.* (1968) evaluated the effect of dietary dilution with a high-density diluent (sand) or a low-density diluent (wood cellulose) on performance of finishing pigs. Diluents were added to replace an equal quantity of the total corn-soybean meal diet such that all dietary ingredients were diluted equally. Results are presented in Table 5.

With sand as a diluent, gains were not affected when less than 40% sand was fed. With cellulose as the diluent, gains were reduced linearly as dietary cellulose level increased. Feed consumption was decreased linearly by graded levels of cellulose dilution. Conversely, dilution with sand tended to increase feed consumption but the increase was not sufficient to maintain nutrient consumption

Table 5. Performance of finishing pigs fed graded levels of sand or cellulose [a,b]

Item	Diluent	% diluent 0	10	20	40
Daily gain, kg[c,d]	sand	0.71	0.78	0.71	0.64
	cellulose	0.76	0.68	0.48	0.25
Daily feed intake, kg[c,d]	sand	2.54	2.84	2.79	2.93
	cellulose	2.63	2.42	2.00	1.50
Gain/feed[d,e]	sand	0.279	0.275	0.254	0.218
	cellulose	0.288	0.281	0.240	0.167

Baker *et al.* (1968)

[a]Each value is a mean of eight individually-fed pigs.

[b]Av. initial weight was 52 kg - 6 wk experiment.

[c]Significant (P<.05) difference between diluents.

[d]Significant (P<.05) diluent source x diluent level interaction.

[e]Significant (P<.05) linear effect due to diluent level.

equal to that of pigs fed the basal diet containing no sand. Based on total feed consumption (including sand), feed efficiency decreased linearly as diluent level increased. Due to the poorer performance of pigs fed cellulose compared to those fed sand at the two higher levels of dilution, the interaction of diluent source x level was significant. The data suggest that finishing pigs can be induced to increase their feed intake above normal levels. Levels up to 20% dietary sand failed to reduce significantly either rate of weight gain or energy consumption. In contrast, pigs fed diets diluted with a low-density diluent (cellulose) showed no compensatory feed intake response.

Nutrient adequacy of the diet being diluted and method of dilution can have a major effect on performance. Animals fed a protein or amino acid deficient diet often exhibit a marked growth response when fiber is added to the diet at the expense of the major energy source. However, when fiber replaces constituents of the total diet, no growth response is obtained. When the diet is made adequate in the limiting nutrient, growth rate then is often depressed by fiber addition. Thus, a narrowing of the calorie-protein ratio, manifested as increased feed consumption, may overcome a nutrient deficiency. In such instances, however, diluent substitution for total diet would not be expected to cause a growth response but undoubtedly would effect a compensatory feed intake response (Baker *et al.*, 1968).

Hydration capacity. Low *et al.* (1978) noted an inverse relationship between dry matter digestibility (measured at the ileum and feces) and the amount of water in the digesta and feces, suggesting that the more digestible a diet is, the less water is required for its digestion and absorption. Kass *et al.* (1980) found that digesta from pigs fed high fiber (alfalfa meal) diets contained less dry matter and that this was associated with a faster rate of fecal passage through the tract, resulting in less digestion of dry matter, nitrogen and cell

wall components. The nature and content of the fiber in diets are factors known to influence the water content of digesta. The finer the grind of material, the lower the water-binding capacity. This indicates that diet particle size may have an important influence on the amount of water contained in the digestive tract. Plant fibers themselves have a characteristic hydration capacity, with vegetable fibers tending to have higher and brans and purified fibers lower values (Table 6).

Table 6. Hydration capacity of various plant fibers

Isolated Fiber	Hydration Capacity, ml/g
Potato	26.8
Rutabaga	21.7
Broccoli	18.5
Celery	18.1
Onions	17.4
Cucumber	16.5
Ryegrass	14.7
Bagasse	8.6
Cellulose	8.6
Alfalfa	7.2
Wheat Straw	6.8
Orchardgrass	6.7
Corn bran	6.6
Wheat bran	6.5
Solka floc	4.7

Van Soest, 1976

Ion exchange capacity. This property of dietary fiber will be discussed in a subsequent section.

EFFECT OF DIETARY FIBER ON DIGESTION AND PERFORMANCE MEASUREMENTS

Digestibility and utilization of fibrous feeds is generally recognized as being lower in swine than in ruminants but there is current evidence that the ability of the pig to utilize dietary fiber has been underestimated (Pond, 1981). The cecum and colon are inhabited by microflora capable of hydrolyzing and fermenting fibrous materials to yield available energy for the host. The extent of digestibility of fiber and of the whole diet is determined by the rate of digestion and the time the residues can remain in the digestive tract (Van Soest, 1977). This time is determined by the rate of passage and the capacity of the digestive tract. Thus, extent of digestion is set by the competitive rates of digestion and passage in any one animal. Rate of digestion is predetermined by the chemical and physical constitution of the feed, leaving passage or intake the only variables that can be set by the animal in response to the diet. The consequence of increasing intake of a fibrous feed is a decline in digestibility (Van Soest, 1975). Since fiber is the least digestible fraction, it largely accounts for the depression.

Digestion of fiber by non-ruminants is limited mainly by the retention time in the lower gut and the potential digestion rate of the fiber (Van Soest, 1977).

Growth of the cellulolytic bacteria depends on their generation time and the feed passage rate. The result is that the pig can utilize rapidly digestible fiber sources (e.g. legumes, brans, fleshy vegetables) as well as ruminants but are very limited in the use of fiber from slower digesting dietary fibers that have higher cell wall content (McQueen and Van Soest, 1975).

Incorporating forages into swine diets has gained renewed interest within recent years. Research at the University of Nebraska has focused on diets for gestating sows. Peo (1975) suggested that feed costs could be reduced by 4 to 10 cents per head per day for gestating sows by including alfalfa or prairie hay into their diet. Although economic benefits of forages in sow gestation diets may appear promising, the value of such diets would be diminished if they were not nutritionally adequate.

Pollman *et al.* (1978) fed three experimental diets (97% sun-cured alfalfa, 66% tall wheatgrass and corn:soybean meal) to gestating sows. Diets and chemical composition of diets are outlined in Tables 7 and 8.

Table 7. Composition of gestation diets

	Diet		
Ingredient, %	Alfalfa	Wheatgrass	Corn:soybean meal
Alfalfa hay, sun-cured	96.75	--	2.5
Wheatgrass, tall, sun-cured	--	66.0	--
Corn, yellow	--	12.9	77.2
Soybean meal (44%)	--	17.8	15.0
Dicalcium phosphate	--	2.0	3.125
Limestone, ground	--	.275	.875
Sodium phosphate	2.4	--	--
Salt, iodized	.5	.5	.5
Trace minerals	.1	.1	.1
Vitamin premix	.25	.425	.7

Pollman *et al.* (1978)

All diets were pelleted. Daily feed allotment resulted in an isocaloric intake for all treatments (5000 kcal/hd/day) although considerable differences in protein intake occurred. Backfat depletion, pregnancy weight gain and reproductive performance were used as response criteria.

Sows fed the corn:soybean meal diet gained more weight during gestation and had a greater amount of backfat at parturition than those fed the forage diets (Table 9). As fiber content of the diets increased, digestibility of the fiber components, energy and nitrogen decreased. Dry matter digestibility of the forage diets was greater at day 80 than at day 30 of gestation. Apparently more nutrients from the forage diets were utilized as the digestive system became more accustomed to the fibrous diets. However, Kass *et al.* (1980) found that no adaptation to fiber diets occurred using growing barrows. There was no difference in the reproductive performance of sows fed the three test diets, although survival rate was higher for pigs from sows fed the corn:soybean meal or alfalfa diets compared to the tall wheatgrass-fed group (Table 10).

Table 8. Chemical analyses of gestation diets

Item[a]	Diet		
	Alfalfa	Wheatgrass	Corn:soybean meal
Dry matter, %	90.0	91.1	89.5
Crude protein, %	16.8	11.8	14.0
Ca, %	1.19	.74	.72
P, %	.87	.65	.65
Cellulose, %	24.3	24.2	4.6
Hemicellulose, %	5.3	16.1	4.6
Lignin, %	7.0	4.4	.7
Total fiber, %[b]	36.6	44.7	9.9
Gross energy, Mcal/kg	4.17	4.10	4.17
Calculated ME, Mcal/kg	2.03	2.24	3.05
Daily intake/sow, kg	2.46	2.23	1.64

Pollmann *et al.* (1978)

[a]All analyses reported on as-is basis.

[b]Cellulose + hemicellulose + lignin.

Table 9. Effect of roughage in sow diets on backfat thickness[a] and pregnancy weight gain[b]

Diet	Week of gestation							Change
	0	2	4	8	10	14	16	+, (-)
Alfalfa								
Backfat thickness, mm	17.2	17.3	17.5	17.0	16.0	15.7	--	(1.5)
Weight, kg	177	173	176	175	179	194	201	24
Wheatgrass								
Backfat thickness, mm	19.5	16.8	17.7	17.9	17.2	15.0	--	(4.5)
Weight, kg	182	176	177	179	182	184	189	7
Corn:soybean meal								
Backfat thickness, mm	16.1	16.5	19.0	20.8	21.3	19.6	--	(3.5)
Weight, kg	173	171	177	183	190	200	214	41

Pollman *et al.* (1980)

[a]Measurements represent six sows per treatment probed by ultrasonic determinations on three pre-designated locations and averaged.

[b]Average weights of six sows per treatment weighed at two week intervals.

Pollmann *et al.* (1980) reported results from an experiment using 88 sows fed sun-cured alfalfa or corn:soybean meal diets through three successive gestations. Both diets were pelleted and fed at the rate of 6000 Kcal of metabolizable energy

Table 10. Effect of roughage in diets of sows on reproductive performance

Criterion	Diet		
	Alfalfa	Wheatgrass	Corn:soybean meal
Number of sows	5	6	6
Farrowing			
Number live	10.0	10.8	11.2
Stillborn	1.0	1.2	.5
Mummified fetus	0[a]	1.0[b]	.5[b]
At 7 days			
Number live	8.6	8.7	9.8
Avg wt, kg	2.46	2.28	2.48
At 14 days			
Number live	8.4	8.3	9.7
Avg wt, kg	3.81	3.79	4.40
Survival rate, %	84.0[a]	76.9[b]	86.6[a]

Pollman *et al.* (1980)

[a,b]Significantly different (P<.05).

per head per day for the first 90 days of gestation (alfalfa, 2.36 kg/hd/day; corn:soybean meal, 1.95 kg/hd/day). Diet composition is found in Table 11.

Table 11. Composition of diets fed to sows

Ingredient	Diet	
	Alfalfa	Corn:soybean meal
Corn, yellow	35.97	76.94
Soybean meal (44%)	10.00	15.00
Alfalfa, sun-cured	50.00	2.50
Salt, iodized	.50	.50
Dicalcium phosphate	--	3.81
Monosodium phosphate	2.25	--
Limestone, ground	.20	.15
Trace minerals	.10	.10
Vitamin premix	1.00	1.00

Pollman *et al.* (1980)

Sows were fed a 14% crude protein diet from day 90 of gestation to farrowing (2.73 kg/hd/day) and fed *ad libitum* post-farrowing. Sows were weighed before breeding and at days 90 and 109 of gestation. Pigs were weighed at birth and on day 14 postpartum. Pigs were not creep-fed but had access to sow feed. Water was available *ad libitum*. Litters were weaned at three weeks of age.

All sows were pen-mated with continual boar exposure for 60 days post-weaning. Sows were removed from the study for any of the following reasons: (1) three or fewer pigs saved from the previous farrowing, (2) death, (3) rectal or vaginal

prolapse, or (4) physical abnormalities of the feet, legs or vulva.

Even though they averaged less weight gain during gestation (16.8 kg/hd vs. 26.3 kg/hd), a higher percentage of sows fed the alfalfa diet completed the study than those fed the corn:soybean meal diet (Table 12).

Table 12. Effect of additions of alfalfa to gestation diets on sow longevity

Item	Gestation diet treatment	
	Alfalfa	Corn:soybean meal
Sows failing to complete three gestations, %	11.1	34.1
Number of sows culled	5	15
Reasons for culling:		
Poor performance[a]	1	4
Death	1	3
Prolapse	1	2
Physical abnormalities[b]	2	6

Pollmann *et al.* (1980)

[a]Saved three or fewer pigs from previous farrowing

[b]Feet, legs and vulva

Although there were no significant differences noted between diets for the number of live pigs, stillborns or mummified fetuses, there was a significant reduction in birth weight for those pigs farrowed by alfalfa-fed sows (Table 13). Average pig weight at 14 days was not affected by sow dietary treatment; however, the number of live pigs at 14 days was 8% greater for the alfalfa-fed sows. The average number of days from weaning until the next farrowing was not affected by diet (alfalfa, 130.5; corn:soybean meal, 132 days).

A variety of other fibrous feeds have been substituted in substantial amounts for cereal grains without adverse effects on weight gain of growing-finishing swine. Substitutions of rice mill feed, cottonseed hulls, oat hulls, soybean hulls and corn cobs as weight for weight replacements of cereal grains or corn have been conducted successfully. The growing pig can apparently tolerate wide levels of fiber in the diet if digestible energy is sustained by inclusion of high energy feedstuffs (Pond, 1981). Wheat by-products (Hanrahan and O'Grady, 1970; Frape *et al.*, 1969; Patience *et al.*, 1977) and corn by-products (Wahlstrom *et al.*, 1970; Cornelius *et al.*, 1977; Harmon *et al.*, 1975a,b) have been shown to be suitable energy sources for swine but their inferior amino acid balance limits their usefulness as protein sources.

It is often difficult to compare results from studies where high fiber diets have been used since the implementation of the experiments is considerably different between investigators (Kennelly and Aherne, 1980a). Some workers ensure that the high fiber diet is maintained isonitrogenous but no attempt is made to maintain a constant digestible energy level (Hochstetler *et al.*, 1959; Baird *et al.*, 1970). In other instances, the control diet is simply diluted with the fiber

Table 13. Effect of dietary additions of alfalfa on sow productivity

Item	Reproductive cycle		Dietary Treatment: Alfalfa	Dietary Treatment: Corn:soybean meal
No. litters				
	1		44	41
	2		42	36
	3		39	28
		Total	125[a]	105[b]
No. live pigs				
	1		11.0	11.1
	2		11.5	11.2
	3		12.2	11.2
		Avg	11.6	11.2
Avg. birth wt, kg				
	1		1.45	1.51
	2		1.33	1.41
	3		1.39	1.48
		Avg	1.39[a]	1.46[b]
No. live pigs at 14 days				
	1		8.6	7.6
	2		9.0	7.8
	3		9.5	8.3
		Avg	9.0[a]	7.9[b]
Avg. 14 day wt, kg				
	1		3.85	3.86
	2		3.87	4.13
	3		2.79	3.78
		Avg	3.83	3.92

Pollmann *et al.* (1980)

[a,b]Significantly different (P<.05).

source, resulting in decreased energy density and with protein quality and quantity changing with the protein content of the fiber source (Axelsson and Eriksson, 1953; Ademosun, 1976; Coey and Robinson, 1954). Finally, the high fiber diet may be formulated to be of a nitrogen and digestible energy content similar to that of the control diet (Baird *et al.*, 1970; Merkel *et al.*, 1958; Forbes and Hamilton, 1952). Also, the way in which an animal will respond to a high fiber diet will be influenced by the physical and chemical composition of the total diet, the level of feeding, the age and weight of the animal, adaptation to the fiber source, individual differences among animals and individual differences among microbial populations within an animal's gastrointestinal tract.

Kennelly and Aherne (1980a,b) conducted an experiment where they examined the influence of various dietary protein and energy levels on performance and metabolism criteria using growing swine. Diets fed and chemical analyses of diets are listed in Table 14. Pigs on treatment 1 were fed a diet suitable for growing swine containing 17.1% crude protein and 4.1% crude fiber. Dietary treatments 2,

Table 14. Formulation, composition and proximate analysis of experimental diets

Diet no.: Diet:	(1) Control	(2) Isonitrogenous	(3) Simple dilution	(4) Isonitrogenous and isoenergetic
Ingredients (%, as fed)				
Barley	50.0	35.4	39.0	40.0
Wheat	31.5	20.0	24.5	--
Soybean meal (48% CP)	15.0	19.1	11.7	23.0
Oat hulls	--	22.0	22.0	22.0
Iodized salt	0.5	0.5	0.4	0.5
Calcium phosphate	1.0	1.0	0.8	1.0
Calcium carbonate (38% Ca)	1.0	1.0	0.8	1.0
Vit. mineral mix	1.0	1.0	0.8	1.0
Tallow	--	--	--	11.5
	100.0	100.0	100.0	100.0
Analyses (as fed)				
Dry matter, %	86.6	88.8	88.2	85.6
Gross energy, MJ/kg	17.10	17.00	16.80	20.70
Digestible energy, MJ/kg	14.10	12.20	12.50	14.70
Nitrogen, %	2.74	2.72	2.30	2.77
Crude fiber, %	4.10	9.80	9.60	10.20
Neutral detergent fiber, %	19.04	29.90	30.00	29.30
Acid detergent fiber, %	5.40	11.80	10.80	12.40
Ether extract, %	2.13	1.97	2.02	15.60
Ash, %	5.32	6.27	5.46	5.46

Kennelly and Aherne (1980a)

3 and 4 were formulated to contain equal crude fiber levels of 10.0% with most of the fiber arising from the addition of 22% ground oat hulls to each diet. Performance results are noted in Table 15. In the growing period, energy dilution resulting from the inclusion of 22% oat hulls had no significant influence on feed intake. Pigs fed high fiber diets increased their feed intake in the finishing period suffiently to achieve digestible energy intakes greater than or similar to those of pigs fed the control diet. It is not clear whether the increased feed intake of pigs fed diets 2 and 3 in the finishing period was a result of the increased age of the animal and/or microbial adaptation to the dietary fiber.

Average daily gain in the growing period was closely related to digestible energy intake and was significantly greater for control pigs than for those fed

Table 15. Feed and crude fiber (CF) intakes, daily gain and feed/gain of pigs from 22 to 63 kg, 63-92 kg, and overall

Diet no: Diet:	(1) Control	(2) Isonitrogenous	(3) Simple dilution	(4) Isonitrogenous and isoenergetic
Period 1 (22-63 kg) - growing				
Initial wt, kg	22.9	22.7	22.0	22.9
Daily feed intake, kg	2.01[a]	2.19[a]	2.17[a]	1.86[c]
Daily CF intake, g	82.4[a]	214.7[b]	208.3[b]	189.7[c]
Daily gain, kg	0.75[a]	0.68[b]	0.66[b]	0.66[b]
Feed/gain	2.71[a]	3.22[b]	3.31[b]	2.79[a]
Period 2 (63-92 kg) - finishing				
Daily feed intake, kg	3.32[a]	4.12[b]	3.66[ab]	3.20[a]
Daily CF intake, g	135.60[a]	404.50[b]	351.70[c]	326.10[d]
Daily gain, kg	0.84	0.80	0.78	0.81
Feed/gain	3.83[a]	5.22[b]	5.12[b]	3.90[a]
Overall (22-92 kg)				
Daily feed intake, kg	2.80[ab]	3.08[b]	3.00[ab]	2.52[a]
Daily CF intake, g	115.40[a]	300.90[b]	288.50[b]	257.20[c]
Daily gain, kg	0.81[a]	0.75[b]	0.72[b]	0.75[b]
Feed/gain	3.25[a]	4.14[b]	4.24[b]	3.33[a]

Kennelly and Aherne (1980a)

[a-d]Means in the same row with unlike superscripts differ ($P<.05$).

the three other diets. However, as the pigs increased in age and/or adapted to the high fiber diet, their ability to eat to digestible energy requirements resulted in average daily gains similar to those obtained on the control diet. While there were no significant differences due to the addition of 22% oat hulls in the finishing period, the control animals gained significantly faster overall. Experiments have been conducted where swine failed to maintain digestible energy intake. This could be attributed to changes in diet acceptance due to excessive levels (bulk effect) or inhibitory substances in the fiber source. Many of the results attributed to the energy dilution effect of fiber or the effect of fiber *per se* are more likely to be due to changes in acceptance of the diet (Kennelly and Aherne,1980a). Also, inclusion of fiber in these diets did not significantly influence any carcass measurements although dressing percentage tended to be reduced. Coey and Robinson (1954) suggested that the reduced dressing percentage, associated with larger gut fill, contributed at least in part to the lower backfat sometimes observed following addition of fiber to swine diets. The lower carcass weight of animals fed high fiber diets place them at a younger physiological age and consequently lower carcass fat.

Another experiment was conducted by Kennelly and Aherne (1980b) to determine digestibilities of various dietary nutrients by 67 kg pigs. Results are presented in Table 16. Depressions in gross energy and dry matter digestibilities were observed with increasing dietary fiber levels. Nitrogen digestion was unaffected by treatment. When the fiber source does not contribute a significant amount of the dietary protein, the effect of fiber on protein digestion is likely to be negligible. Digestibility coefficients for crude fiber, NDF and ADF were consistently higher for pigs fed the low-fiber diets than for those fed the high-fiber diets. The addition of the high level of fat in diet 4 depressed fiber digestibility.

Table 16. Nutrient digestibilities

Diet no.: Diet:	(1) Control	(2) Isonitrogenous	(3) Simple dilution	(4) Isonitrogenous and isoenergetic
Digestibility, %				
Gross energy	82.4[a]	71.9[b]	74.6[b]	71.0[b]
Dry matter	81.4[a]	70.2[b]	72.8[b]	65.0[c]
Nitrogen	82.0	82.7	79.1	81.7
Ether extract	78.0[a]	78.6[a]	76.2[a]	94.3[b]
Crude fiber	27.7[a]	20.8[a]	24.9[a]	14.7[b]
Neutral detergent fiber	57.8[a]	39.5[b]	46.7[c]	32.6[d]
Acid detergent fiber	20.7[a]	13.9[ab]	17.0[a]	8.5[b]

Kennelly and Aherne (1980b)

[a-d]Means in the same row with unlike superscripts differ (P<.05).

DIETARY FIBER AS AN ENERGY SOURCE FOR SWINE

The significance of microbial digestion to the ruminant is well known. Production of volatile fatty acids (VFA) has been estimated to supply 70-80% of the animal's energy requirement (Bergman *et al.*, 1965). While it is accepted that the disappearance of dietary fiber during the passage of feedstuffs through the digestive tract of non-ruminant animals is the result of fermentation or microbial action (Argenzio and Southworth, 1975), direct observations on the degree to which the apparently digested fiber is utilized are few and contradictory (Kass *et al.*, 1980). Contributions of VFA to the swine energy requirement varies from 5-28% of digestible energy intake (Friend *et al.*, 1964; Farrell and Johnson, 1972; Imoto and Namioka, 1978) depending on the quantity of fermentable carbohydrate in the gut and the amount reaching the lower gastrointestinal tract. Kass *et al.* (1980) found that VFA disappearing from the lower gastrointestinal tract were equivalent to 79, 147, 227 and 155 kcal/day for pigs fed 0, 20, 40 or 60% alfalfa meal, respectively, at 48 kg body weight and 47, 231, 285 and 245 kcal/day, respectively, at 89 kg body weight. VFA produced in the large intestine provided 6.9, 11.3, 12.5 and 12.0% of the energy required for maintenance in the 48 kg pig and 4.8, 11.4, 14.0 and 12.0% in the 89 kg pig fed 0, 10, 40 or 60% alfalfa meal, respectively.

In the pig, the transport of VFA through the cecal and colonic mucosa is very efficient (Argenzio and Southworth, 1975) and complete (Farrell and Johnson, 1972). This is supported by the occurrence of VFA in the efferent blood of the intestine (Barcroft *et al.*, 1974) and in the peripheral blood (McClymont, 1951; Friend *et al.*, 1964) during digestion.

It is now well established that the energy value of feed ingredients for swine is greatly influenced by their fiber content. A negative linear relationship between apparent digestibility of energy and level of crude fiber in the diet exists. Henry (1977) showed a linear relationship between the rate of decrease of apparent digestible energy (ADE) and level of fiber such that, for every one percentage unit increase in crude fiber, there was a decrease in ADE, the extent of which varied with the feedstuff (Table 17). It is interesting to note that the correction factors for crude fiber are closely related to the composition of cell wall constituents. The higher the acid detergent fiber/neutral detergent fiber ratio, the lower the depressive effect of fiber on ADE. The greatest decrease in ADE is induced by wheat bran, as well as certain milling by-products, which contain a higher proportion of hemicellulose coresponding to a low acid detergent fiber/neutral detergent fiber ratio. Henry (1977) concluded that, for predicting the energy value of swine diets, the neutral detergent fiber content was found to be the best indicator of the fiber fraction (as compared to crude fiber or acid detergent fiber), especially in the case of complete diets with various sources of fiber. Better precision may still be obtained if the partition of cell wall constituents is considered, for instance, by calculating the acid detergent fiber/neutral detergent fiber ratio or cellulose/hemicellulose ratio.

Table 17. Constant factors for correcting digestible energy of swine feeds for crude fiber content

Ingredient	Correction factor[a]
Wheat bran, dry milled	3.0
Maize, gluten with bran, wet milled dehy	2.6
Oats, grain	2.2
Alfalfa, aerial part, dehy ground	2.1
Barley, grain	1.5
Horsebean, seeds	1.2
Pea, field, seeds (fodder peas)	1.2
Beet, sugar, pulp, dehy	1.1

Henry (1977)

[a]Rate of decrease of ADE per one percent increase in crude fiber content.

FIBER UTILIZATION AS AFFECTED BY FEED ADDITIVES

The role of feed additive (antibiotics, monensin) supplementation of high fiber diets on nutrient utilization by swine is poorly understood. In an early study (Bohman *et al.*, 1955), weanling pigs were fed four levels of alfalfa meal (0, 10, 30 or 50% of the diet) with or without aureomycin (22 mg/kg feed) in balanced, pelleted diets. Diets containing no alfalfa were composed of 75.3% ground milo and 24.7% protein supplement and all diets were made isonitrogenous.

As level of dietary alfalfa increased, average daily gain decreased significantly (Table 18). However, when aureomycin was added to the diets, rate of gain significantly increased. As level of dietary alfalfa increased, the difference in rate of gain between pigs receiving aureomycin and those fed control diets decreased. However, aureomycin increased feed efficiency even at the highest level of alfalfa feeding.

In a recent study (Powley *et al.*, 1981), several additives (ASP-250, bentonite, glutamic acid and wheat bran) were included in a barley-soybean meal diet containing 40% alfalfa meal and fed to 54 kg pigs. ASP-250 was fed to determine whether antibiotics influence utilization of high fiber diets. Glutamic acid was used to determine whether performance would be improved if the bitter taste of alfalfa was masked. Bentonite and wheat bran were used in an attempt to reduce the watery consistency of feces (scouring) observed when high alfalfa diets are fed. ASP-250 was the only additive to provide a better response than the 40% alfalfa meal diet with no additives (Table 19).

Table 19. Gain and feed efficiency of pigs fed 40% alfalfa with various additives

Diet	Avg. daily gain, g	Feed/gain
0 alfalfa	870[a]	3.3
40% alfalfa	640[b]	4.5
40% alfalfa + ASP-250	690[c]	4.2
40% alfalfa + bentonite	650[b]	5.5
40% alfalfa + glutamic acid	610[d]	4.2
40% alfalfa + wheat bran	580[e]	5.2

Powley *et al.* (1981)

[a,b,c,d,e]Values with different superscripts differ (P<.05).

When wheat-soybean meal diets were supplemented with ASP-250 with or without 30% alfalfa meal, it was noted that no decrease in performance occurred with the inclusion of alfalfa meal yet the antibiotic was effective in improving average daily gain, regardless of whether the diets contained alfalfa meal (Table 20). The response to ASP-250 by pigs fed alfalfa meal-supplemented diets was of the same magnitude as for the control diet, suggesting that the effect of the drug was not specifically to improve alfalfa utilization.

Table 20. Performance of pigs fed 0 to 30% alfalfa with or without ASP-250

	0 alfalfa		30% alfalfa	
Item	No drug	ASP-250	No drug	ASP-250
Avg daily gain, g	670[a]	760[b]	640[a]	730[b]
Feed/gain	2.8	2.9	3.6	3.5

Powley *et al.* (1981)

[a,b]Values in same row with different superscripts differ (P<.01).

Table 18. The effect of aureomycin and graded levels of alfalfa upon growth and feed utilization

	Aureomycin				Controls			
Level of Alfalfa, %	0	10	30	50	0	10	30	50
Average, lbs								
Initial weight	38	37	37	37	37	37	38	33
Final weight	203	213	209	203	212	202	207	206
Daily gain*	2.07	1.85	1.45	1.01	1.82	1.72	1.37	1.01
Daily feed consumption, lb	6.0	6.1	5.5	5.2	5.6	5.7	5.4	5.4
Feed per lb gain, lb	2.98	3.35	3.87	5.24	3.06	3.57	4.04	5.40
Concentrate per lb gain, lb	2.98	3.01	2.71	2.62	3.06	3.21	2.83	2.70

Bohman *et al.* (1955)

*Difference between alfalfa levels is significant (P<.01).

Sherry *et al.* (1981) found that supplementation of corn-soybean meal diets with 8% cellulose and ASP-250 and fed to weanling pigs resulted in a significant fiber x antibiotic interaction which depressed resting metabolic rate (Table 21).

Table 21. Metabolic rate data[a]

Item	Treatment			
	Control	Cellulose	ASP-250[b]	ASP-250 + Cellulose
Respiratory quotient	.93	.90	.91	.81
O_2 consumed, liters O_2/kg/day[b]	15.79	16.92	18.22	15.30

Sherry *et al.* (1981)

[a]Each value represents the mean for six pigs (three replicates of two pigs).

[b]Antibiotic x fiber effect ($P<.05$).

This indicates that less heat was lost to the environment during the postprandial state which should result in increased energy utilization. The greater feed efficiency by animals fed the cellulose-antibiotic diet supported this finding. The absence of enhanced fiber digestibility and N retention due to the fiber x antibiotic interaction and the decreased metabolic rate in animals fed the ASP-250 + cellulose diet indicate that improved performance was due not to increased energy or nitrogen obtained from the diet, but rather to increased efficiency in utilization of the energy present. This effect is probably mediated by the intestinal microbes. Because the microbial population is affected by both fiber and antibiotic, and because it can affect metabolic rates at the animal level, a change in the microbial population is likely responsible for the depressed metabolic rates of animals due either to changes in species or metabolism of the microbes present.

Additions of other antibiotics negatively affect fiber digestion. Gargallo and Zimmerman (1980) fed cecal-cannulated pigs a corn-soybean meal diet supplemented with 150 mg neomycin sulfate/kg body weight (100 mg in the feed and 50 mg directly into the cecum via the cannula). The coefficients of apparent digestibility for dry matter and cellulose are shown in Table 22. Both decreased as dietary cellulose increased. The addition of neomycin completely arrested the digestion of cellulose which corroborates the microbial origin of fiber digestion.

Another additive that has been tested to a lesser extent is monensin, a widely used feed additive for beef cattle. Monensin supplementation generally results in improved feed efficiency, presumably by increasing ruminal propionic acid levels and proportionally decreasing ruminal acetic and butyric acid levels (Richardson *et al.*, 1976). Since the microflora and VFA (acetic, propionic, butyric) ratios that appear in the forestomachs of ruminants are similar to those that appear in the cecum and large intestine of pigs, it is possible that monensin supplementation of high fiber diets could prove to be useful. DeBarthe and Kane (1980) fed eight cecal cannulated barrows a 14% crude protein diet containing either 11 mg/kg monensin, 23% solka floc or both. VFA data are presented in Table 23. The addition of solka floc depressed the total concentration of VFA.

Table 22. Effect of dietary cellulose level on dry matter and cellulose digestibility (percentage)

Cellulose level, %	Dry Matter		Cellulose	
	No antibiotic[a]	Antibiotic[a]	No antibiotic[b]	Antibiotic[c]
2	83.93	82.01	42.43	.0
10	75.90	73.54	21.78	.62
18	68.28	70.74	10.44	2.83

Gargallo and Zimmerman (1980)

[a]Linear effect of cellulose level ($P<.05$).

[b]Linear and quadratic effect ($P<.05$).

[c]Antibiotic effect ($P<.01$).

However, neither the monensin main effect nor the solka floc x monensin interaction was significant. The basal diet with monensin resulted in higher total VFA concentrations than did the solka floc diets but not higher than did the basal diet. Monensin significantly reduced the ratio of acetic to propionic acid, apparently by both increasing propionic and decreasing acetic acid concentrations.

Table 23. Effect of solka floc and monensin on cecal VFA

Diet	Total VFA,[a] mmoles/liter	% Concentration[b]			
		Acetic acid	Propionic acid	Butyric acid	Acetic/Propionic
Basal	113.9[c,d]	57.3	28.1	14.6	2.04[d,f]
Basal + monensin	127.5[d]	52.9	36.8	10.3	1.44[c,e]
Basal + solka floc	106.3[c]	55.4	32.9	11.7	1.68[c,e,f]
Basal + solka floc + monensin	104.9[c]	51.0	36.7	12.3	1.39[c,e]

DeBarthe and Kane (1980)

[a]Sum of acetic, propionic, and butyric acids averaged over all sampling times.

[b]Percent of total acetic, propionic, and butyric acids.

[c,d]Values in the same column bearing different superscripts differ ($P<.05$)

[e,f]Values in the same column bearing different superscripts differ ($P<.01$).

EFFECTS OF DIETARY FIBER ON MINERAL METABOLISM

Diets rich in fiber have a different mineral content from diets containing small quantities of fiber. Minerals in plant feeds are often closely associated with the plant cell wall and are involved in the structural framework and binding of the cellular polysaccharides (Rees, 1976). In mixed diets, an element is derived both from the mineral intimately associated with the fiber of the plant cell wall and from the mineral present in free form. If fiber remains undigested as it passes through the small intestine, the mineral associated with the cell wall itself will remain unavailable for absorption from the small intestine. If the binding capacity of the fiber exceeds that of the plant's own minerals, minerals from other food sources will be complexed and thus rendered less available for absorption.

The traditional view that mineral absorption can take place only in the small intestine is becoming increasingly untenable. An element may still be absorbed by the colon once the plant cell wall and associated structures are digested by microbial fermentation within the colonic lumen; the complex is thereby destroyed and the element is more readily transported into the body (James *et al.*, 1978).

The importance of colonic absorption of minerals has been demonstrated in pigs by Partridge (1978) who inserted re-entrant cannulae in the terminal ileum so that he could distinguish between absorption from the small intestine and from the colon. On a low cellulose (3% solka floc) diet, approximately 43% of the very high Ca intake was absorbed in the small intestine, but an additional 31%, amounting to about 4 g/day of Ca, was absorbed from the colon (Table 24). Thus the colon is making a substantial contribution to Ca balance in a growing pig fed a low-cellulose diet.

Table 24. The fraction of dietary minerals and phosphate absorbed in the small and large intestine of pigs fed low- and high-cellulose diets[a]

	Low-cellulose diet				High-cellulose diet			
Mineral	Intake[b] g	Small intestine %	Colon %	Total %	Intake[b] g	Small intestine %	Colon %	Total %
Sodium	5.1	46	53	99	5.6	15	83	98
Potassium	4.6	90	7	97	4.3	88	-2	86
Calcium	13.5	43	31	74	13.2	44	19	63
Phosphate	9.9	64	17	81	10.2	69	5	74
Magnesium	10.9	-1	74	73	1.14	3	56	59
Zinc	0.12	10	50	60	0.13	24	32	56

Partridge (1978)

[a]Pig size taken as 48 kg as suggested by Partridge.

[b]Intake includes the estimate of mineral intake from tap water.

Of greater interest is the response to the high-cellulose (9% solka floc) diet. Despite a twofold increase in ileal flow rates, Ca absorption from the small intestine was similar. There was, however, a substantial fall in colonic Ca transport so that fecal Ca output increased. The combined absorption of Ca by

the small and large intestine fell from 74% to 63% of intake. A reduction in colonic phosphate absorption was also apparent on the high cellulose diet. This study also revealed that colonic absorption of Mg and Zn was particularly important for maintaining mineral balance. Mg excretion increased when cellulose was fed. Zn absorption anterior to the terminal ileum was enhanced with the high cellulose diet, although not sufficiently to offset the reduced absorption from the colon. Thus with the low-cellulose diet, the large intestine was the principal site of Zn absorption with little occurring anterior to the terminal ileum; with the high cellulose diet, the relative importance of the two intestinal regions was reversed.

Large amounts of mineral can apparently be absorbed by the colon of the growing animal. Due to this fact, the mechanism whereby fiber leads to elemental malabsorption needs to be re-evaluated. If fiber binds minerals by complexing them with its functional groups, the observation that mineral balance can be preserved probably depends upon the fiber being hydrolyzed by colonic bacteria with subsequent absorption of the mineral from the cecum and colon.

In a study using graded levels of wheat middlings substituted for corn in practical corn-soybean meal diets (Collings *et al.*, 1979), a decrease in apparent Ca and P absorption was noted with increasing levels of wheat middlings in the diet (Table 25). The reduction in apparent P absorption may have been due to an increase in phytate P when the amount of middlings in the diet was increased. This could also have affected Ca absorption.

Table 25. Apparent absorption of calcium and phosphorus as influencedby dietary level of wheat middlings

	Percentage wheat middlings			
Item	0	10	20	30
Calcium absorbed, % of intake[a]				
Starter	71.1	67.9	51.8	44.3
Grower	57.5	56.0	28.8	38.4
Finisher	59.9	46.2	47.4	41.7
Phosphorus absorbed, % of intake[b]				
Starter	71.0	64.5	59.4	46.7
Grower	45.2	57.3	36.0	43.5
Finisher	35.8	48.9	39.1	27.7

Collings *et al.* (1979)

[a]Linear regression of % calcium absorbed on % wheat middlings in diet is Y=-.96X + 73.2, r =-.972 (starter); Y =-.84X + 57.8, r = -.782 (grower); Y = -.53X + 56.8, r = -.884 (finisher).

[b]Linear regression of % phosphorus absorbed on % wheat middlings in diet is Y = -.78X + 72.1, r= -.978 (starter); Y= -.26X + 49.5, r = -.386 (grower); Y = -.24X + 44.0, r = -.296 (finisher).

No effect of diet, however, was observed in plasma Ca and P, indicating that the pigs were maintaining a normal physiological balance of Ca and P, despite a decrease in apparent absorption. Plasma Zn appeared to be reduced by treatment but the effect was inconclusive because of high individual variability.

GENETIC DIFFERENCES BETWEEN BREEDS OF SWINE IN THEIR ABILITY TO UTILIZE FIBER

The genetic makeup of swine and method of feeding may influence dietary fiber utilization by growing-finishing pigs. Steele and Frobish (1976) showed that genetic phenotype of swine was the main factor regulating lipogenic enzyme activities rather than dietary manipulations such as feeding frequency (*ad lib* vs. meal-fed) and dietary energy source (starch vs. lard).

Pond *et al.* (1980) compared responses of genetically obese, lean and contemporary growing pigs fed diets containing 0 or 20% alfalfa meal. Duroc x Yorkshire pigs comprised all genetic groups. Alfalfa meal decreased daily weight gain and gain:feed for all genetic groups. The magnitude of differences among groups in daily gain associated with dietary alfalfa meal was similar in the early growing and finishing periods, suggesting no adaptation to alfalfa meal with advancing age. The similar reduction in daily gain among all genetic groups in response to dietary alfalfa meal provided no evidence of genetic differences related to body fatness in the pig's ability to utilize dietary fiber.

Recent experimental evidence indicates that rate of feed ingestion is inversely related to efficiency of digestion and conversion of feed to lean tissue in swine. Petersson (1979) compared two diets of different energy content fed in a manner to equalize daily energy intake by growing-finishing pigs. Pigs fed the low energy diet required longer daily feeding periods. However, their growth was as rapid, lean tissue content greater and conversion of feed to lean tissue superior to that of pigs fed the high energy diet. Concurrent digestibility trials showed high digestion coefficients for pigs fed the low energy diet. These results may reflect a reduction in rates of energy ingestion, increased gut stimulation provided by a higher non-energy content of the diet, a decreased rate of food passage through the digestive system, or a combination of these factors.

Changes in diets to accommodate increasing competition for cereal grain supplies will necessitate continuous review and revision of performance testing procedures (Fredeen, 1980).

ECONOMIC CONSIDERATIONS

Projections have been made relative to the extent of use of forages and by-product feeds in future swine production at different efficiencies of productivity and at different levels of demand for pork (Pond, 1981). Cunha (1980) suggested that pigs marketed per sow yearly could reasonably be increased from the current 13 to 24 by appropriate management and that feed/gain could be improved from the current 3.5 to 2.5 kg of feed per kg body weight gain. Such improvements in these two production traits would result in a reduction by one-third in the feed required to produce a 110 kg slaughter pig (385 vs. 263 kg feed). Swine consume about 72% of their entire diet as grain, 11.6% as protein supplements, 2.1% as milling and distillers by-products and 14.3% as forages (CAST, 1977). If an annual U.S. hog slaughter of 80 million is assumed, the total feed requirement for swine production is 30.8 million metric tons at present. If swine production efficiency could be improved as suggested by Cunha (1980), a saving of 9.8 million metric tons of feed would be realized. This feed could support the production of 37.1 million additional hogs for slaughter.

CONCLUSIONS

The pig is more efficient than any other farm mammal or bird in gross feed energy conversion to food energy for man (17% of gross feed energy is converted to food energy by the pig compared with 12% for poultry, 5% for lamb and 4% for beef) (Cook, 1977). Pork ranks behind poultry and milk but ahead of beef and lamb in the efficiency with which edible protein is produced per unit consumption of protein or energy by the animal (Pond and Kass, 1977). Research results indicate that milling and distillers by-products could be used at 20% of the total diet in the overall swine production enterprise without a significant reduction in performance. Similarly, forage use could be increased from the present 14% to 20-25% of total feed (Pond, 1981). Substitution of forages and by-product feedstuffs in swine diets could result in significant conservation of feed grain energy, approaching a 40% saving in feed grain use under present conditions and perhaps app-oaching 60% if reproduction rates and efficiency of feed utilization by market swine attain projected levels (Pond, 1981).

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Pig Energetics–The Diet and the Environment

STANLEY CURTIS

INTRODUCTION

The foundation of profitable pork production is sound swine husbandry. As economic pressures in the pork industry continue to mount, more refinement of biological-management technics will be required. Producers who do not respond to these demands in a timely fashion will watch their enterprises fall. High on the list of necessary production skills in this era is the ability to manage energy--feed energy and fuel energy. Several specific aspects of the pig's nutritional and environmental energetics will be explored in this paper.

DIETARY ENERGY

Energy metabolism in the pig--the phenomenon which Max Kleiber (1961) poetically called The Fire of Life--is the driver of all of the physiological processes exploited in pork production. The source of that energy is the feed.

Partition of Dietary Energy

The pig cannot use all of the chemical-bond energy in its ration (National Research Council, 1981a). That part of the dietary energy consumed (intake energy) which is not digested, together with the energy in certain compounds of metabolic origin, appear as fecal energy. The difference between intake energy and fecal energy is called digestible energy. As discussed by Fahey and Holzgraefe (1981), the digestibility of feedstuffs (digestible energy/intake energy) varies mainly with the chemical nature of the material (Table 1).

The pig uses metabolizable energy to drive maintenance and productive processes. The metabolizable energy eventually becomes the energy of some product of the pig (such as meat, milk, or fetus) or else it is lost to the environment as heat. This heat originates in the maintenance processes themselves and in the heat increment of feeding. The heat increment, in turn, is the heat produced during processing of the feed by the gastrointestinal tract and processing and use of absorbed nutrients by the body. It thus reflects energetic inefficiency, unless the pig can use the heat to maintain its body temperature in a cold environment (Curtis, 1981).

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Table 1. Energy values of some common feedstuffs for swine

Feedstuff[a]	Dry matter (%)	Energy content (kcal/kg), as fed, in thermoneutral environment			Heat increment (%)[d]
		Intake[b]	Digestible[c]	Metabolizable[c]	
Alfalfa meal, dehy. (1-00-025)	92	4119	2238	2033	79
Barley (4-00-530, 4-00-549)	89	4084	3080	2876	34
Corn (4-02-935, 4-92-931)	89	3918	3525	3325	31
Lard (4-94-790)	100	9323	7763	7703	--
Oats (4-03-309, 4-03-315)	89	4187	2866	2668	49
Soybean meal (5-04-604)	89	4198	3300	2825	41
Soybean oil (4-07-983	100	9396	7562	7284	25
Wheat (4-05-211, 4-05-268)	89	4001	3520	3277	30
Whey, dried (4-01-182)	93	3821	3401	3270	32

[a]Number within parentheses is International Feed Number.

[b]From National Research Council (1969), except dehydrated alfalfa meal and dried whey values from Ewan (1979).

[c]From National Research Council (1979), except barley and wheat values from National Research Council (1969) and dehydrated alfalfa meal and dried whey values from Ewan (1979).

[d]Derived from Ewan (1979).

Dietary-Energy Digestibility and Environmental Temperature

The idea that the digestibility of dietary energy is affected by the thermal surroundings of the animal ingesting the ration is a new one (National Research Council, 1981b). Available evidence supports the conclusion that dietary-energy digestibility is related directly with environmental temperature. This effect appears to be apart from other influences such as feed-intake and digesta-passage rates. Fuller and Boyne (1972) found that in growing-finishing hogs occupying environments where the temperature ranged from 5°C to 23°C, dietary-energy digestibility rose by 0.12 percentage unit per Celsius degree increase in environmental temperature. Likewise, Phillips *et al.* (1980) reported that in swine maintained at a constant environmental temperature over the range of 6°C to 20°C, dietary-energy digestibility increased by 0.27 percentage unit per Celsius degree rise in temperature.

Dietary-Fat and -Fiber Concentrations and Environmental Temperature

The heat increment of feeding depends on several factors, including dietary composition (Curtis, 1981). Armstrong and Blaxter (1957) summarized data from

various sources indicating that when swine were fed at slightly above the maintenance level the heat increments of feeding (kcal/100 kcal of metabolizable energy) for fat, carbohydrate, protein, and mixed diets were 9, 17, 26, and 10 to 40, respectively. More recent estimates of the heat increments--as a percentage of metabolizable energy--of common feedstuffs, as summarized by Ewan (1979), are listed in Table 1.

It follows that by adding fat to a diet, the heat increment is lowered. The magnitude of the heat increment is also related to the nature and the amount of fiber in the diet; the higher the dietary fiber concentration, the greater the heat increment. If it is assumed that tallow's and lard's heat increments are similar to that of soybean oil, the heat increment of dehydrated alfalfa meal is at least three times that of these fat sources.

The heat increment of feeding can be a burden in a warm environment or a help in a cool one (Curtis, 1981). Stahly (1981) has discussed the value of intentional dietary alterations in relation to environmental temperature. The value of the addition of fat in the form of tallow or lard, which have low heat increments, to a swine diet at the rate of 5% is greater during warm weather than during cool (Tables 2 and 3).

Table 2. Effect of season on pigs' responses to added dietary fat[a]

	Performance change due to added dietary fat (%)	
Trait	Winter	Summer
Daily body-weight gain	+0.9	+8.3
Feed/gain ratio	-8.5	-11.3

Stahly *et al.* (1981)

[a]Average starting weight was 25 kg; finishing, 93 kg. Concrete-floored open-front houses were used. Foggers operated when air temperature exceeded 29°C. Weekly maximum air temperature averaged 4°C in winter trials; 29°C in summer.

Table 3. Added value ($/metric ton) over standard diet of a swine diet containing 5% added fat, as function of environmental temperature and feed price[a]

Feed price ($/metric ton)	Cool environment (10°C or lower)	Warm environment (15°C to 29°C)
132	12.76	22.66
176	17.16	28.38
220	21.34	33.88
264	25.30	39.60
308	29.26	45.32

Stahly (1981)

[a]Assuming average yearly herd productivity = 82 kg live-weight gain (18 kg to 100 kg body weight) per pig, 266 kg feed per pig, 110-day feeding period; feed is 16%- or 14%-crude protein, corn-soybean meal-based diet; fixed costs = $.135 per pig per day, with facilities operating at capacity; fat contains low levels of water and unsaponified material.

On the other hand, the value of adding fiber in the form of dehydrated alfalfa meal, which has a high heat increment, to a swine diet at the rate of 5% of 10% is greater during cool weather than during warm (Tables 4 and 5).

Table 4. Effect of season on pigs' responses to dehydrated alfalfa meal (DAM) added to the diet[a]

	Performance change due to added dietary DAM (%)	
Trait	Winter	Summer
Daily body-weight gain		
5% added DAM	+1.4	-4.1
10% added DAM	-4.7	-7.2
Feed/gain ratio		
5% added DAM	-2.1	+7.0
10% added DAM	+2.8	+7.7

Stahly *et al.* (unpublished data)
Funderburke *et al.* (1980)

[a]Pigs fed diets with 5% added fiber were in an open-front house in Western Kentucky; those fed diets with 10% added fiber were in a curtain-sided, naturally ventilated house in Northern Georgia.

Table 5. Value of dehydrated alfalfa meal ($/metric ton) added to a diet at a rate of up to 10%, as function of environmental temperature and feed price[a]

Feed price ($/metric ton)	Cool environment (daily maximum temperature 7°C or lower)	Warm environment (daily maximum temperature 16°C or higher)
132	101.20	-0-
176	138.60	7.70
220	176.00	15.40
264	213.40	25.30
308	250.80	35.20

Stahly (1981)

[a]Assuming same standards as in footnote to Table 3.

NUTRITIONAL AND ENVIRONMENTAL ENERGETICS

Management decisions having to do with the economics of energy--feed energy and fuel energy--are very important, because feed and fuel account for such a large part of the cost of swine production.

Body-Temperature Regulation

Swine are homeothermic animals: Over a fairly wide range of environmental temperature, their body temperature remains roughly the same. To achieve homeothermy when environmental temperature is below the lower critical temperature, the

animal must increase its metabolic heat-production rate. It must burn extra feed in the process, leading to inevitable inefficiency in the conversion of feed to animal products. The alternative in a given climatic region is to raise the temperature of the animal's microenvironment above the lower critical temperature, so thermoregulatory heat production will not be triggered. But this requires the burning of extra fuel or the use of extra electricity. Relative prices of feed and fuel affect decisions bearing on the question as to whether it would be more economical to keep environmental temperature in an animal house low and let the animals compensate by eating more feed, or to hold the temperature at a higher point and thus spare some feed from being used as fuel.

Effective Environmental Temperature

In recent years results of research in several laboratories around the world have made it possible to quantify the effects of a cool or cold environment on the pig's feed needs (Mount, 1975; Holmes and Close, 1977; Verstegen *et al.*, 1978).

In order to extend scientific findings in this area to practical conditions and to make comparisons among different environmental situations, a composite index of the thermal environment must be used. This is called effective environmental temperature--the temperature of an isothermal, still environment that results in the same environmental heat demand from an animal as the environment being considered (Curtis, 1981). For pigs weighing 45 lb, for example, three factors combined with air temperature give a useful estimate of the total impact of thermal factors in the surroundings on the animal's heat budget (Mount, 1975). Starting with air temperature, the index is estimated by accounting for air speed at pig level, for the type of floor used, and for the insulation value of the walls (which in turn determines inside wall temperature for a given air-temperature difference between inside and outside).

An animal's convective heat-loss rate is roughly proportional to the square root of air velocity in the microenvironment (Curtis, 1981). It is known empirically (Mount, 1975) that if air speed at pig level is 0.5 ft/sec, 7 F^{o} must be subtracted from air temperature as the first step in estimating effective environmental temperature; if 1.5 ft/sec, 13 F^{o}; and 5 ft/sec, 18 F^{o}.

Floor type also affects effective environmental temperature (Curtis, 1981). Mount (1975) deduced from available data that when straw is on a solid floor, 7 F^{o} are *added* to air temperature in arriving at the next stage of effective-environmental-temperature estimate. A slotted concrete floor requires subtraction of 10 F^{o}; a solid concrete floor (assumed to be wet), subtraction of 15 F^{o}.

The effect of cool surfaces inside the house to which heat can be lost by radiation is the final stage of correction of air temperature to estimate effective environmental temperature. The temperature of inside wall and ceiling surfaces (Ts) can be estimated from the relation published by ASHRAE (1972): $(R_1/R_2)= ((Ti - Ts)/(Ti - To))$, where R_1 (=0.67) is the boundary-layer resistance to heat flow from indoor air to the surface at which Ts is estimated, R_2 is the overall resistance to heat flow of the wall from indoor air to outdoor air, Ti is indoor air temperature, and To is outdoor air temperature.

For example, when To is $0^{o}F$ and Ti is $70^{o}F$, a wall with an R_2 value of 2 results in a Ts of $47^{o}F$. The temperature gradient between the animal's and the environment's radiant surfaces is thus increased by ($70^{o}F = 47^{o}F$) or 23 F^{o} over the isothermal situation where air and radiant-surface temperatures are the same,

and it has been found (Mount, 1975) that in this case 13 F^{o} must be subtracted from air temperature to arrive at effective environmental temperature. Likewise, for R_2 values of 8, 14, and 20, respectively, Ts under the same conditions of Ti and To would be 64° F, 67°F and 68°F, respectively, and the correction is to subtract 3 F^{o}, 2 F^{o}, and 1 F^{o} to achieve the final effective-environmental-temperature estimate (Mount, 1975).

Combining all of the corrections just discussed for a practical situation, consider a house in which air temperature is 60°F when outside temperature is 0°F, and where air speed at pig level is 1.5 ft/sec, the floor is slotted concrete, and the R_2 value of the walls and ceiling is 14. The effective environmental temperature would be (60°F - (13 F^{o} + 10 F^{o} + 2 F^{o})) or 35°F. How does such an effective environmental temperature affect the pig's need for feed? This example will serve as the basis for the quantitative examination of energy relations in swine production which follows.

Effective Environmental Temperature and Feed Requirement

A pig's lower critical temperature depends in part on the animal's rate of feed intake. Consider a 45-lb pig. When it is consuming just enough feed to maintain its body weight, its lower critical temperature is 75°F. In other words, if effective environmental temperature falls below 75°F for such an animal, it will need to increase its metabolic rate to produce enough heat to keep its body temperature in the normal range. Of course, any feed the pig has to burn in this way as fuel is not available for productive purposes, so this represents an inefficiency.

Most pigs on farms are not fed at the maintenance level, but rather at some higher level that will support growth. As feed-intake rate increases to two or three times the maintenance level--or on up to the *ad-libitum* level of around 3.2 times maintenance--the 45-lb pig's lower critical temperature drops progressively to 66°F, 59°F, and 55°F. This is due to the heat increment of feeding--the extra internal heat production associated with the processes of ingestion, digestion, and assimilation of food discussed earlier in this paper.

Results of careful research indicate that for each Fahrenheit degree effective environmental temperature is below the lower critical temperature, a 45-lb pig burns an extra 0.016 lb of feed each day (Holmes and Close, 1977; Verstegen *et al.*, 1978). Thus, for instance, a pig in the hypothetical example used in this paper--at a feeding level of 3.2 times maintenance (and thus a lower critical temperature of 55°F), at an effective environmental temperature of 35°F, and thus at (55°F - 35°F) or 20 F^{o} below the lower critical point--would need to consume (20 x 0.16) or 0.32 lb of extra feed daily just to keep its body warm. This represents a 15% increase over the *ad-libitum* feed-intake rate. Over many days, and times many pigs, this kind of inefficiency can add up to represent a sizeable extra cost of production.

Values in Table 6 relate a pig's body weight, lower critical effective environmental temperature at three levels of feed intake (once, twice, or three times maintenance), and the extra feed which must be burned to keep the body warm for each Fahrenheit degree effective environmental temperature is below the critical temperature.

Fuel Requirement for Supplemental Heat

The extra fuel required to raise environmental temperature inside a swine

Table 6. Lower critical temperature (°F) of swine of different body weights and at different levels of feed intake and extra feed required to fight cold

Body weight (lb)	Feeding level (increment of maintenance) 1 X	2 X	3 X	Extra feed[a]/day per F degree EET is <LCT (lb)
5	81	75	75	.005
45	75	66	59	.016
130	73	64	55	.036
220	72	63	54	.043
310	73	64	54	.055

Holmes and Close (1977)

[a]Assumed 1410 kcal of metabolizable energy per pound.

house to the thermoneutral zone (above the lower critical temprature) is calculated on the basis of the amount of supplemental heat required to compensate for the additional total heat loss (building heat loss plus ventilation heat loss) that would result from increasing the temperature gradient between inside air and outside air. Of course, the rates of building and ventilation heat losses for a given inside temperature are related inversely with outside temperature at any given time.

In the hypothetical example, the difference between the actual and the lower-critical effective environmental temperatures is (55°F - 35°F) or 20 F°. Hence, in order to raise effective environmental temperature by the 20 F° necessary to reach the pig's thermoneutral zone, additional supplemental heat must be generated.

A house for 100 45-lb pigs might measure 20 ft by 20 ft with an 8-ft ceiling. Thus, total wall and ceiling surface area (A)--the area over which most building heat loss occurs--would be 1040 square feet. If it be assumed that the average R_2 value of the walls and the ceiling is a typical 14, then the additional building heat-loss rate resulting from an additional 20 F° in the inside-to-outside temperature gradient (ΔT) would be $((A)(\Delta T))/(R) = ((1040)(20))/(14) = 1485$ Btu/hr ≃ 35,000 Btu/day as a first approximation (Curtis, 1981).

Two variables affect the rate of ventilation heat loss: the ventilation rate and the temperature gradient. The product of these two values times the volumetric heat capacity of air yields the ventilation heat-loss rate (Curtis, 1981). In the hypothetical case being developed, it can be shown that a ventilation rate of 2 cu ft/min per pig (200 cu ft/min for the whole house) is appropriate in terms of maintaining proper moisture balance. In this case, when the temperature gradient is widened by 20 F°, the additional ventilation heat loss is ∿110,000 Btu/day for the whole house.

Combining these two avenues of heat loss, the total heat-loss rate for the swine house of this example would be increased by around 150,000 Btu/day if inside air temperature were raised by 20 F° in order to achieve an effective microenvironmental temperature of 55°F or above--in the thermoneutral zone for 45-lb pigs being fed *ad libitum*.

This additional supplemental heat could be generated in several ways. Assum-

ing the heat came from an oil-fired heater releasing 140,000 Btu of heat per gallon of fuel oil burned (a liberal assumption), then (150,000/140,000) or ∿1.1 gal of extra fuel oil would be required each day to keep effective environmental temperature above the pigs' critical point.

Feed or Fuel?

The economic alternatives in the feed-or-fuel question for this hypothetical situation come down to 32 lb of feed per day for the 100 pigs residing in an environment with an effective temperature of 35°F (20 F° below thermoneutrality) as opposed to 1.1 gal of extra fuel oil per day to keep the whole house 20 F° warmer. A table of the ratio--extra feed cost/extra fuel cost--as a function of variable feed and fuel prices shows that now (Fall 1981) the extra feed (at $120/T) would still cost more than the extra fuel (at $1.20/gal), so in most situations the decision would be to set the thermostat up in order to spare feed's being burned as fuel. If a lower feed price or a higher fuel-oil price occurred--a distinct possibility, it would seem--then the ratio would become even narrower, and the decision as to which alternative to favor would be more critical.

Table 7. The ratio--extra feed cost/extra fuel cost--for the hypothetical case developed in the text, as a function of different prices of feed and of fuel

Feed price ($/T)	Fuel-oil price ($/gal)					
	0.8	1.0	1.2	1.4	1.6	1.8
200	3.6	2.9	2.4	2.1	1.8	1.6
180	3.3	2.6	2.2	1.9	1.6	1.5
160	2.9	2.3	1.9	1.7	1.5	1.3
140	2.5	2.0	1.7	1.5	1.3	1.1
120	2.2	1.7	1.5	1.3	1.1	1.0
100	1.8	1.5	1.2	1.0	0.9	0.8
80	1.5	1.2	1.0	0.8	0.7	0.6
60	1.1	0.9	0.7	0.6	0.5	0.5

OPERANT SUPPLEMENTAL HEAT

Pigs can survive--but not necessarily thrive--in a wide range of thermal conditions because various temperature-regulating mechanisms can be employed. Behavioral patterns greatly facilitate the pig's thermoregulatory capacity. Huddling and the selection of a comfortable environmental niche are two such strategies.

But today's confined swine are often prevented from selecting an optimal temperature. For example, during cold weather, environmental temperature in closed nursery facilities is frequently kept relatively uniform over space and constant over time. This approach deprives young pigs of the chance to select an environment more comfortable than the one chosen by the manager. Still, in this era of high energy costs, the manager must minimize fuel use in pork production.

Operant Conditioning

Operant conditioning is one way pigs can regulate the thermal environment by

themselves. Operant conditioning is a type of learning in which the animal acquires new response patterns based on past experiences. The operant response is made voluntarily by the animal, and this has an effect on the environment. If the environment is rewarding, providing something such as feed or water or warmth, the animal will tend to repeat the response. If the environmental effect is non-rewarding, the animal will stop responding in this way.

Pigs are aided in their search for resources, such as thermal comfort, a refuge, or a mate, by what they have learned through their experiences. They learn to repeat new responses that produce reward. For example, swine can adjust their thermal environment during cold periods by becoming operantly conditioned to perform a task in which heat serves as the reward. Baldwin and Ingram (1968) found that individually held pigs showed a frequency of operant responses for a three-second burst of infrared heat that was inversely proportional to environmental temperature. Balsbaugh and Curtis (1979) found similar results for pigs treated differently in two respects: the pigs were held in groups, instead of singly, and they were given much longer infrared-heat rewards, of one, three, or six minutes. These results suggested that operantly controlled supplemental heat might be feasible in swine production systems.

Balsbaugh and Curtis (1979) also found that pigs in a warm environment will deactivate or turn off heat lamps more often as the lamps' total wattage output is increased. In addition, pigs in groups consistently demonstrated a preference for cooler surroundings at night, regardless of whether they were activating heat lamps in a cool environment or deactivating them in a warm one.

Operant Control of Supplemental Heat in Nurseries

A study conducted in the winter of 1979-80 demonstrated that pigs in groups in a practical nursery situation learned to operate a switch in order to obtain a ten-minute reward of heat from four heat lamps (Morris *et al.*, 1980). This response further determined the thermal environment for the pigs in other pens in the house by also controlling the natural-gas-fired unit heater that provided supplemental heat. The performance and general health of these pigs were comparable to those of animals produced in commercial nurseries.

A Performance Experiment

During the winter of 1980-81, a study was conducted to determine if pigs that control the thermal environment by themselves perform as well as pigs kept in a constant-temperature, thermostat-controlled environment (Morris and Curtis, 1981). Three trials were conducted in a continuously illuminated nursery house. The house had a totally slotted steel floor and was divided into two sections by means of an insulated partition having an R value greater than 13. A natural-gas-fired heater was located 0.9 m above the floor in each room. Each heater was equipped with a gas meter to determine the therms (1,000 Btu) equivalent of gas used. An exhaust ventilation fan was located on the north wall in each section.

An operant activation switch was placed in the pen judged to be receiving the least amount of heat from the heater in the operant-controlled-supplemental-heated section (OSH). (Sections were alternated between treatments from one trial to the next.) Four heat lamps were suspended above the operant switch to ensure immediate reward so the conditioned response would be reinforced psychologically.

The switch was enclosed in a metal box. A hinged paddle in the center of one side was connected to a microswitch. A protective metal casing surrounded the box. It had an opening which allowed a pig access to the paddle, which was recessed. Pressure on the paddle closed the microswitch for an instant, which allowed electrical current to pass to a solenoid, which in turn activated two time-delay relays, which in turn controlled current flow through the heat lamps and the unit heater, respectively.

The solenoids were such that heat lamps and unit heater were normally off till the switch was operated. Each time the heat lamps and the unit heater responded, they were activated for periods of ten and eight minutes, respectively. Switch operation while the ten-minute time-delay relay was active was without effect. However, each switch operation, as well as each period the unit heater was on, was monitored by a strip-chart event recorder.

This management technique was compared to a thermostat-controlled-supplemental-heated section (TSH) in which the unit heater's thermostat was set at 26.7°C at all times for the duration of each trial.

A minimum-temperature thermostat set at 1.7°C was used in the OSH section as a precautionary measure to keep the temperature above the freezing point. A hygrothermograph recorded inside room temperature and relative humidity continuously in each section. Outside temperature data came from a weather station located 2 km away.

A total of 528 pigs--264 on each treatment--were used in this experiment. They were weaned at an average age of four weeks in all three trials of the experiment. Pigs were allotted to treatments and pens randomly, after accounting for body weight and litter. There were 8 pigs per pen.

The temperature in both sections was set at 26.7°C the first day the pigs were in the house. The TSH section was maintained at this temperature for the duration of each trial, while the temperature in the OSH section was gradually reduced to 1.7°C by day 4, which is the day performance measurements actually started. This scheme in the OSH section was used to entice the pigs to condition themselves to use the operant switch. Pigs were observed closely the first few days of each trial to ensure that the pen of pigs that controlled environmental temperature for the whole OSH section indeed had learned to activate the heat lamps. In all cases, they had.

There was no significant difference in body-weight gain or gain/feed ratio between the two treatments. TSH pigs on average gained 0.38 kg per day, while OSH pigs gained 0.39 kg per day. Gain/feed ratio was 0.50 for both treatments. Mortality rate was higher in the OSH section (4.9%) than in the TSH (2.3%). We have no explanation for this, but believe that intervention with antibiotics--precluded by the experimental design--would have saved some of those that died.

Relative fuel usage was calculated by dividing the number of therms of fuel used in the OSH section by those used in the TSH. A 53% saving in fuel was found in the OSH section over all trials. It is assumed that this is largely because the inside-to-outside temperature gradient was markedly smaller in the OSH section than in the TSH. The fuel savings in individual trials indicate the OSH system was more fuel-conservative the lower the outside temperature. In the trial conducted during the coldest weather, there was a 73% saving of fuel.

Hygrothermograph records showed that the temperature in the TSH section did indeed remain fairly constant over time, while that in the OSH section followed a definite daily cycle. The temperature in the OSH section peaked for awhile each day at the temperature maintained constantly in the TSH section. This suggests that the environmental temperature usually recommended as optimal is actually needed by the pig for only a short period each day--around the middle of the day--and at other times the temperature could be reduced.

The average daily maximum and minimum air temperatures in the OSH section are listed in Table 8. There was as much as an 11 C^{o} difference between daily maximum and minimum temperatures under the OSH system, while temperature in the TSH section varied less than 3 C^{o} above or below 26.7 ^{o}C.

Table 8. Daily maximum and minimum environmental temperatures (^{o}C) in section of house in which young pigs controlled supplemental heat operantly

Trial	Average daily maximum temperature	Average daily minimum temperature
1	27.1	15.7
2	27.0	14.3
3	24.8	15.3
All	26.3	15.1

These results indicate that the performance of young pigs given the opportunity to control the thermal environment by themselves can be equal to that of pigs produced in more conventional, thermostat-controlled nurseries. Also, these pigs can be as much as 73% more efficient in fuel usage than the more conventionally housed pigs. Operant control of supplemental heating can be used in swine nursery houses, but the management requirement of this system is relatively high.

Diurnal Temperature Cycles

Another way to take advantage of the apparent economic benefits of a cyclic thermal environment for young pigs would be to use a diurnally cycling thermostat or to simply set a standard thermostat "up" each morning and "back down" each evening.

CONCLUSIONS

Nutritional and environmental energetics are inextricably coupled. Environmental temperature influences the digestibility of a diet as well as the usefulness of such dietary additives as fiber and fat sources. Effective environmental temperature is determined by several important thermal forces in the surroundings. The level of feed intake is a major determinant of a pig's lower critical temperature, which in turn is a major determinant of the extra feed an animal must burn to keep its body warm in a cold environment. There is an economic trade-off between the feed used to support this thermoregulatory heat production, on the one hand, and the fuel used to keep effective environmental temperature above the lower critical point, on the other. Finally, there is good evidence that even young pigs do not require a constant thermal environment, and the saving of fuel

obtained from letting the pigs' environmental temperature fall each night can be substantial.

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Energy Conservation Alternatives in Swine Production

JAMES A. DESHAZER, DAVID P. SHELTON, AND GERALD R. BODMAN

Energy conservation in swine housing requires continual observance of the surroundings, sensitivity to the environmental needs of the pigs, and knowledge of the principles of heat transfer in order to manage a swine production facility in an energy efficient manner. This article is to acquaint you with energy conservation alternatives and the importance these can have on energy utilization within a swine enterprise.

A comprehensive energy management program must begin with careful observation. We are all rushed in keeping up with commitments--often just barely keeping our "heads above water"--but right now take just a few minutes to look around the farmstead and observe. Refrain from jumping to a new job or problem, just observe and ask a few questions about energy conservation alternatives. Are windbreaks being used to protect buildings from direct winds, thereby reducing heat loss? Have all components of the ventilation system been kept clean and maintained? Are the fans of the proper capacity? Are the air inlets cleaned and properly adjusted? Are doors and windows tight-fitting and weather-stripped? Is non-mechanical ventilation employed where feasible? Are the buildings oriented for maximum solar benefits? Have the heating system components been cleaned, serviced and adjusted within the last year? Are the thermostats properly located, cleaned, and set at the correct temperature? Are the buildings properly insulated? (Don't forget perimeter insulation). Were vapor barriers used to protect the insulation from water vapor condensing in the walls and ceiling? Are the buildings tight and in good repair? The list of similar questions is practically endless, but these questions indicate which methods of conserving energy needs further attention.

Let us concentrate on methods of conserving the heating or cooling requirement of a swine building. The supplemental heating (or cooling) requirement for a swine building depends upon (1) air temperature maintained inside the building, (2) the outside building temperature, (3) the amount and placement of insulation, (4) quantity of air moved through the building, (5) orientation and location of the building, and (6) the heat production of the pig. The primary areas of heat loss are building components and the ventilation air.

INSULATING

Insulating to conserve building component heat loss or gain is important. During cold months insulated building surfaces will provide warmer walls and hence

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decrease the heat loss of the pig and the chances of moisture forming on building surfaces.

The effectiveness of a material to resist heat flow is measured in R-values. The unit for R-value is: suface area (ft^2) x time period (hr) x difference between the inside and outside temperatures (°F) ÷ by the flow of energy (BTU). Table 1 presents the R-values for common insulating and building materials.

Table 1. Insulation values of materials

Material	Thickness	R-Values[1/]
Insulation		
Blanket or batt	1"	3.5
Loose fill	1"	2.5-3.0
Vermiculite	1"	2.0
Milled paper	1"	3.1-3.7
Rigid		
Expanded polystyrene		
extruded (styrofoam or formular)	1"	4.0-5.3
molded, 1 lb/cu ft (beadboard)	1"	3.6
Expanded polyurethane	1"	6.2
Building Materials		
Plywood	½"	0.6
Concrete solid	1"	0.1
Concrete block (lightweight	8"	2.0
Air Film and Spaces		
Air space	3/4"-4"	0.9
Inside plus outside air boundary layer		0.85

1/ Resistance values can be added to obtain total resistance of a building component.

A reasonable balance in insulation levels in a building is important. For illustrative purposes, let us assume that the ceiling of a 24 x 60 ft,20-sow farrowing house is insulated with 6 inches of fiberglass batt insulation and the 8 ft sidewalls are uninsulated. This could result in an R-value of 22 for the ceiling and 2.0 for the uninsulated sidewalls. The heat loss potential of the ceiling is calculated by dividing the R-value (22) into the surface area (24 x 60) which results in an energy loss of 65 BTU/hr/°F difference in inside and outside temperature. The calculated heat loss potential of the walls is 672 BTU/hr/°F (10 times greater than the ceiling) with the total being 737 BTU/hr/°F (65 + 672).

Now taking the 720 cu ft (24 x 60 x 0.5) of insulation in the ceiling and distributing it evenly will result in 3.1 inches of insulation being placed in both ceiling and sidewalls. This provides an R-value of approximately 12. Therefore the new heat loss potential of the ceiling is 120 BTU/hr/°F and of the side walls is 112 BTU/hr/°F for a total of 232 BTU/hr/°F--a value of just one-

third of the original value or a 3-fold decrease in the heat loss or gain of the building! Hence, the placement of the insulation is equally as important as the amount being placed.

The wall area below the ground, the foundation wall, is often neglected or overlooked when applying insulation. The recommended 2 inches thick by 2 ft wide foam insulation reduces the perimeter heat loss potential from 136 BTU/hr/°F (more than the insulated wall heat loss) to 76 BTU/hr/°F. Therefore, insulate wisely by totally insulating the building, not just partially insulating.

The current recommended insulation level is presented in Table 2.

Table 2. R-Value recommendation[1/]

Heating Degree	Building Type			
	Modified Open Front		Space Heated	
Days	Walls	Ceiling	Walls	Ceiling
2500 to 6000	6	17	14	25
6000 or more	12	25	20	33

1/ Remember to use perimeter insulation.

VENTILATION CONTROL

Ventilation control is important in limiting ventilation heat loss and still provide fresh air without drafts. Wintertime ventilation requires the warming of the air to increase its moisture holding capacity to remove the moisture produced by the pig. The amount of energy required to heat the air is determined by multiplying a constant (1.1) x the ventilation rate (cfm) x the difference between the inside and outside temperatures (°F). For example, a 20-sow farrowing building being ventilated at 400 cfm will lose 440 BTU/hr by the ventilation system for every degree of temperature rise. This value is greater than the heat loss potential of 308 BTU/hr/°F (120 + 112 + 76) for the building components of the previous example. When the 20-sow farrowing building is insulated to the recommended values the building component heat loss is lowered to 154 BTU/hr/°F (44 ceiling + 34 walls + 76 perimeter) or only 26% of the total facility heat loss. Therefore, 74% of the building heat loss is by ventilation. Note: for every 100 cfm increase in ventilation rate an additional 110 BTU/hr/°F of energy is lost from the building. Hence, you need to adhere to the recommended minimum ventilation rate presented in Table 3 for efficient heating.

All components of a ventilation system need to be periodically cleaned and serviced. Efficient AMCA rated fans should be purchased and kept maintained. Thermostats need to be periodically cleaned and checked for accuracy. Inlets need to be adjusted to maintain proper air distribution, avoid drafts, and maintain the proper static pressures.

PREHEATING VENTILATION AIR

Preheating ventilation air by natural sources is under investigation. Using

the earth as a heat sink by bringing the ventilation air through pipes buried in the soil will both heat the incoming air in the winter and cool it during the summer. Water can condense from the air in the tubes during cooling. Therefore, drains or sumps must be provided. There are many unanswered questions about earth tubes such as the length required and overall system design. In addition, the possibility exists for mold and/or fungi growth in the damp dark tubes, with potential detrimental effects on animal health. Utilization of earth tubes should be approached with caution.

Using solar energy to preheat ventilation air is a feasible way of reducing energy requirements. However, the total system must be carefully designed and employ heat storage for effective use.

Table 3. Winter continuous minimum ventilation rates for pigs.

Sow & Litter	20 cfm
Pre-nursery	
12-30 lb	2 cfm/pig
Nursery	
30-75 lb	3 cfm/pig
Growing	
75-150 lb	7 cfm/pig
Finishing	
150-220 lb	10 cfm/pig
Gestating Sows	
325 ave. lb	12 cfm/hog
Boar	
400 ave. lb	14 cfm/hog

BUILDING PLACEMENT

Building heat loss can be reduced by berming walls with earth to provide a more constant temperature on the outside wall. This will also reduce summer heat gain, making a cooler building. However, earth berming does not eliminate the need for insulating the walls.

The building should be placed with the long axis oriented east-west to provide greater surface area on the south wall for the direct rays of the sun to heat the wall during the winter. In the summer, the wall can be shaded with an eave overhang (approximately 1 ft of overhang for every 2 ft of wall height). Light-colored roofs and good attic ventilation reduce summer heat gains through the roof. Windbreaks will provide a better thermal environment for the building, and decrease air infiltration due to lowered wind pressures.

HEATING TECHNIQUES

Heating techniques may help to conserve energy. Whole house heating occurs when using unit heaters. Therefore heat is provided to the complete house volume. Heat is really needed only where the pig is located. Methods of providing a heated micro-environment will save energy. This can be done by providing a hover area that can be heated with external energy sources and/or heated by the pig's

heat. The hover area can also be heated through solar energy used to heat the floor or by infrared radiation. Infrared radiation can be used in an open room since radiation heats only the objects it strikes, such as the pig's body.

Unvented heaters may require additional ventilation in swine buildings to dispose of the moisture and carbon dioxide generated by the heater. Therefore, the heat conserved by use of unvented heaters could be lost by the increase in the ventilation heat loss.

PIG'S HEAT LOSS

Pig's heat loss is an important source of heat for swine buildings. Table 4 presents the heat loss of different weight pigs at various environmental temperatures. The sensible heat loss of the pig will increase with decreasing environmental temperature and therefore help maintain the building temperature. For example, the heat losses of a 50-lb pig are 300, 240, 210, and 150 BTU/hr at environmental temperatures of 40, 50, 60 and 70°F respectively.

Table 4. Latent, sensible and total heat production of the growing-finishing pig

Weight	Temperature °F	Latent lb H_2O / pig-hr	Sensible BTU / pig-hr	Total BTU / pig-hr
50 lb (Solid floor)	40	0.12	300	430
	50	0.13	240	380
	60	0.14	210	360
	70	0.18	150	340
	80	0.23	80	330
100 lb (Solid floor)	40	0.14	440	590
	50	0.15	350	510
	60	0.18	280	470
	70	0.22	200	430
	80	0.27	140	420
200 lb (Solid floor)	40	0.20	650	860
	50	0.21	520	740
	60	0.22	410	650
	70	0.26	320	600
	80	0.33	220	570

THERMOSTAT SETTING

Thermostat setting or selection of the thermal environment for the pig needs to be evaluated in terms of animal performance and energy savings. The heat loss of the 50-lb pig is enough to maintain the inside air temperature at 40°F with the outside temperature at 10°F. This is in a well stocked and insulated building with a heat loss potential of 8 BTU/hr/°F per pig. Will it pay to supply heat and raise the temperature to 50°F? or 60°F? or 70°F? An increase in air temper-

ature to 50°F, 60°F or 70°F could result in 0.7, 1.1 and 1.1 lb feed savings per lb of gain respectively. The supplemental heat requirement is 8 BTU/hr/°F times the temperature difference minus the heat production of the pig. Therefore, the supplemental heat required at 50°F is 1,900 BTU/day/pig, at 60°F is 4,600 BTU/day and at 70°F is 7,900 BTU/day. The heat requirement increases faster at higher building temperature because of the decrease in the heat loss of the pig with increasing environmental temperatures. If propane is at 0.8¢/1,000 BTU (55¢ per gal) and feed cost is 7¢ per lb, and the thermostat is raised to 50°F then it will cost approximately 1.5¢ more of fuel per day but with 4.9¢ less feed per lb gained. When the thermostat is raised to 60°F, 3.6¢ of fuel is required with 7.7¢ less feed per lb gained. Raising the thermostat from 60°F to 70°F will increase heating cost by 75% (6.3¢ of fuel) with no performance advantages. Therefore, it is important to know the environmental requirement of the pig and not to exceed this requirement to maintain an energy efficient, cost-effective operation.

WASTE AND WATER MANAGEMENT

Waste and water management will influence the energy required to heat a building. The percentage of the building heat load that is sensible and latent will depend upon the methods of handling waste and water in the confinement facility. The evaporation of water in a building will reduce the sensible heat content of the air and increase the latent (moisture) content of air. The total heat loss of the animal will remain the same. For example, a growing-finishing swine facility using a 100% slotted floor showed a 43% reduction in moisture load over that of a swine facility using a solid floor. Computer results have indicated a 25% increase in the slotted floor area can reduce the heat energy consumption by approximately 12%. The evaporization of standing water can contribute, during warm weather, to decreasing building temperature, but be detrimental during cold weather in causing a possible increase in the supplemental heat requirement.

SUMMARY

The major heat loss from a swine building is through the ventilation system. Therefore proper but not excessive ventilation rates need to be employed. Insulating the total building with proper insulation distribution is important for energy conservation and effective use of the insulation.

Interior building temperatures should be maintained to provide comfort to the pig for efficient feed conversion. Decrease the amount of standing water in the building during the winter. Drafty conditions should be avoided by weatherstripping and air inlet adjustments.

The ventilation and heating systems should be properly maintained and cleaned on a regular basis. Infrared heating and/or use of hovers will conserve energy by providing a local satisfying environment to the pig without heating the whole building.

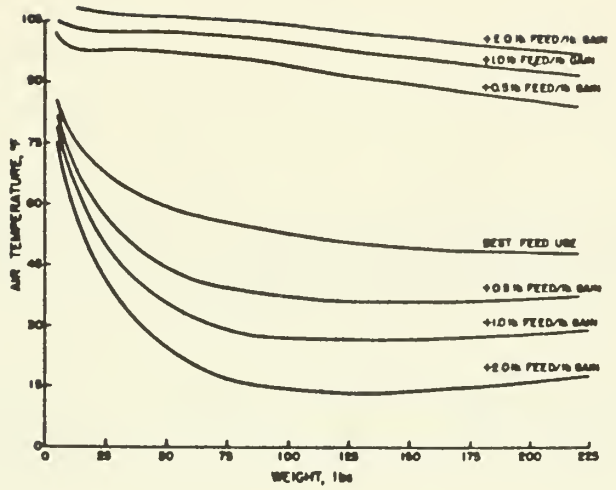

Figure 1. The use of feed per lb. of gain as related to air temperature and body weight.

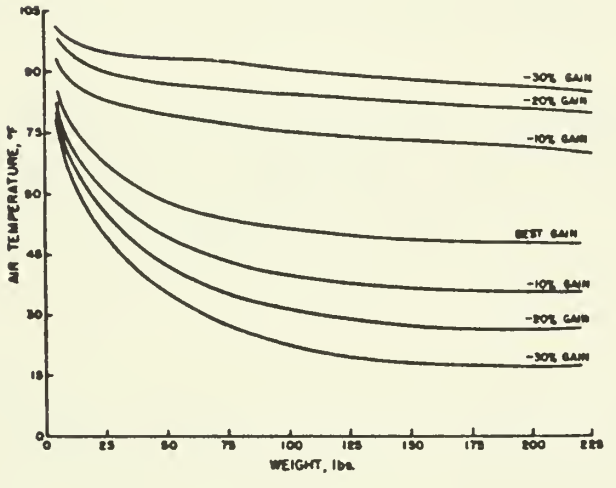

Figure 2. The rate of gain as related to air temperature and body weight.

The Crisis in Agricultural Research

DUANE ACKER

It is a great pleasure to be with you this morning at the University of Illinois and share with you my high regard for the faculty and the leadership of the University of Illinois.

The coming of machines in the middle of the last century made Americans realize their developing industrial system depended upon an efficient agriculture to release manpower to the labor pool and to provide a dependable source of food and fiber.

Federal enabling acts were passed to establish educational, research and extension programs in support of the developing agriculture. Among these were the establishment of the U. S. Department of Agriculture and the passage of the Homestead Act and the Morrill Act in 1862 and the passage of the Hatch Act in 1887.

At that time, Americans had just moved beyond the Appalachian Mountains and had begun to realize the potential agricultural productivity of the new area. In a sense, Congress said through its legislation, "Let's move out. Let's develop agriculture---this enormous potential we can see."

In following years, the Smith-Lever Act of 1914 and the Smith-Hughes Act of 1917 were passed.

Subsequent developments in American agriculture were great. The productivity achieved is referred to often as the "miracle of American agriculture." It was in no sense a miracle but rather the result of continuous public investment of money and trained persons into programs designed to solve problems and to meet the needs of a country rich in resources.

To continue the "miracle" will take continued public investment in talent, time and programs.

Now is the time for this country and for its Congress to recognize that it is agriculture that provides this country a competitive advantage. It is agriculture, not electronics, heavy machinery or any other specific industry. American food and fiber are our greatest export potential and provide our major source of cash flow.

Duane Acker, President, Kansas State University

Agriculture is something this nation does best. It is time for us to prime this sector of the economy and to invest in research, extension and education to keep this section of the U. S. economy supreme.

But, public, particularly federal, support for agricultural research has declined in real terms in recent years. The impact of inflation on research funding is of grave concern.

Data on total research expenditures at SAES and in the USDA in constant and current dollars demonstrate the impact of inflation. In 1967, the combined expenditure of the SAES and USDA was $373,099,000. In 1979, the combined expenditure of the SAES and USDA was---in current dollars---$1,090,172,000, but in constant dollars it was only $463,312,000. This means that the expenditures of these agencies for research in real dollars from 1967 to 1979 increased by only 24 percent or an average of two per cent per year.

It is useful also to compare real dollar total research expenditures at SAES by source of funding---federal, state and private.

Between 1967 and 1979, total research expenditures at SAES from formula funds, cooperative grants and cooperative agreements and all other federal funds increased in real dollars by 17 percent or an average of 1.4 percent per year.

Between 1967 and 1979, total research expenditures at SAES from state appropriations increased in real dollars by 61 percent or an average of five per cent per year.

Between 1967 and 1979, total research expenditures at SAES from private grants increased in real dollars by 75 percent or an average of 6.5 percent per year.

The slowdown in federal funding and the impact of inflation on all funding are critical. We must be concerned by the present difficult economic conditions and by the potential damaging effects these conditions might have on our agricultural capacity.

At all levels of funding---state, private and federal---we must express our concern for the long-run, well-being of the American agricultural system.

We are pleased that President Reagan has recommended an increase in funding for agricultural research---one of a small number of increases in the total federal budget;probably agricultural research, agricultural extension and military are about the only three. Much of the credit goes to an Illinoian John Block and to the respect he has for the agricultural research and extension programs of the University of Illinois and USDA research installations in Illinois.

It is incumbent upon people like you, leaders in your commodity industry, to understand fully the impact of inflation on research funding and to be outspoken on behalf of the needs and benefits of agricultural research.

The public investment in agricultural research has been impressive, and the return on the investment has been even more impressive. And the beneficiaries are many.

The most obvious beneficiary of agricultural research is the consumer. Research that results in improved quality or uniformity of food products permits consumer confidence in buying food. Programs that increase the quantity of food per acre or per unit help hold down unit prices.

The second major beneficiary of agricultural research is J. Q. Public. To begin, the benefits of agricultural research haven't been confined to farm production. Many findings have been applicable to human health (e.g. the discovery, development and use of vitamins, studies of nutritional anemias due to iron and copper deficiencies, iodized salt, blood anti-coagulants, rodenticides, vaccines, antibiotics); to the quality of the environment (e.g. soil and water conservation, game management and reforestation); and to the improvement of humankind's cultural and aesthetic environment (e.g. release of millions of acres from tillage to public parks and wilderness).

Also, the public benefits from increased volume of farm exports which helps our balance of trade, strengthens the dollar and lets us buy consumer goods back from other countries. During fiscal 1981, U. S. farm exports were $44.7 billion; with farm imports valued at $17.4 billion from other countries, the net surplus of our agricultural trade balance is $27.3 billion. This money helps the nation pay for imported oil, for the support of our military troops overseas, for you and me to take a European vacation and for the purchase of Japanese automobiles, motorcycles or computers.

There are other beneficiaries.

Arguments put forth in the 1880's on behalf of the proposed Hatch Act and the description of agricultural research accomplishments since then, center on the idea that research benefits farmers by enabling them to increase output and/or conserve on inputs.

But, we must remember, it is one thing to increase corn production by a million bushels or save farmers a million dollars in expenses and quite another to increase farm income by a million dollars.

Some farmers and ranchers are able to reap short-run profits by early adoption of new inputs or techniques, which explains why most are eager to adopt technology.

But farmers and ranchers are also food and fiber consumers and users of imported goods. They do business with dollars.

Persons in private agri-business benefit from agricultural research. Especially, in the short-run those who process or manufacture specific agricultural products profit by adopting new technology.

In the long-run, the stability and high volume of the agricultural system means profit for many.

Agri-business persons also benefit as consumers and as users of foreign imports.

It is appropriate that we send the bill for agricultural research to those who benefit most.

The bill should be sent to every American who consumes American agricultural foodstuffs and uses American-produced fiber.

The bill should be sent to each American who uses or benefits from the use of foreign oil. (Exportable agricultural products are the major barter this country has).

Send the bill to anyone who uses a foreign-produced automobile, motorcycle, sewing machine, piano, transistor radio, or any one of thousands of foreign products. Dollars from agri-sales were available to buy these products.

Send the bill to that person who travels outside the United States, invests abroad or believes our military forces should be stationed in areas outside our borders.

In other words, the bill should be sent to the American public. The beneficiaries of agricultural research should also be its patrons.

Our agricultural experiment stations and others in agricultural research have produced miracles. There are more to come---miracles reached through the same hard work of dedicated scientists supported by public investment.

We need to know so many more things.

Nutrient requirements for humans are defined either poorly or not at all; in fact, trace elements are better known for some other animal species than for humans. Nutrient deficiencies and excess food intake are problems for different age groups. Replacement of traditional foods by new protein sources and fabricated foods have altered the diet, and there is little knowledge of the nutritional consequences.

We need to develop alternative crop management systems and analyze the impact of taxes and other policy issues on production efficiency of a farm or a region.

We need to identify more practical methods to conserve energy. We need to improve the efficiency of energy utilization in the entire food production and preparation process, from farm to table, and to develop substitutes for fossil fuels. We must manufacture fertilizers with less energy input.

We need to master genetic engineering. We need to "engineer" the genes in the "gene pool", within animal and plant species, so that they can most benefit the human race.

The list goes on and on.

The next "miracle" of American agriculture will come from the scientists' consistent generation of new ideas and of new knowledge.

We must take steps within our states through state legislators to see to it that the state continues to recognize the importance of agricultural research to the economic welfare of the state.

And, we must press for continuing increased federal support for agricultural research.

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